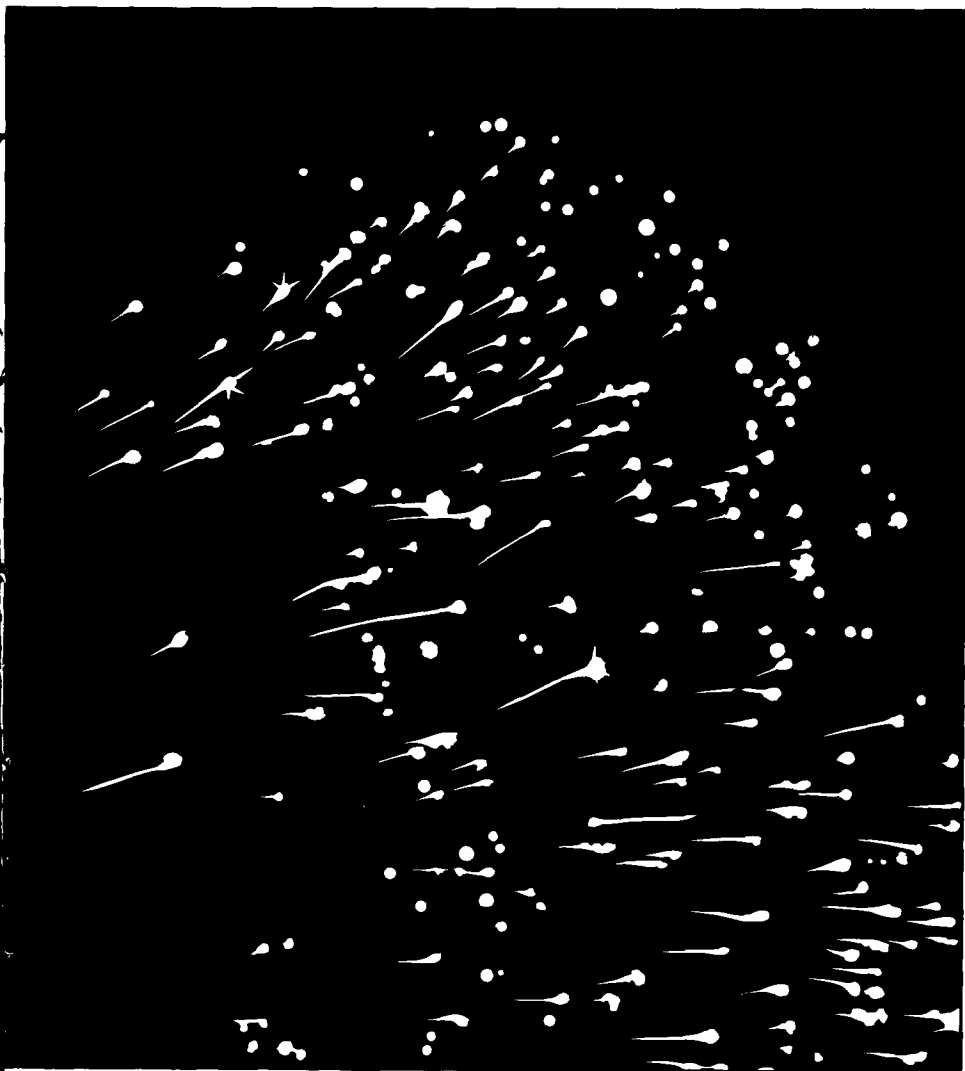


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1979-81  
UNIVERSITY  
OF MINNESOTA  
BULLETIN

**INSTITUTE OF TECHNOLOGY**





UNIVERSITY OF MINNESOTA

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*Cover:* Optical fibers, small-diameter glass filaments used with lasers to transmit telephone and television signals, are replacing traditional wires and cables. Design by Gadbois Art Works.

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The contents of this bulletin and other University bulletins, publications, or announcements are subject to change without notice.

# Institute of Technology

UNIVERSITY OF MINNESOTA

## **DIRECTORY OF DEPARTMENTAL OFFICES**

Office of the Dean, 107 Lind Hall

Office of the Assistant Dean, 105 Lind Hall

Aerospace Engineering and Mechanics, 107 Aeronautical Engineering

Agricultural Engineering, 213 Agricultural Engineering, St. Paul

Architecture and Landscape Architecture, 110 Architecture

Astronomy, 358 Tate Laboratory of Physics

Chemical Engineering and Materials Science, 151 Chemical Engineering

Chemistry, 139 Smith Hall

Civil and Mineral Engineering, 112 Mineral and Metallurgical Engineering

Computer Science, 136 Lind Hall

Electrical Engineering, 139 Electrical Engineering

Geology and Geophysics (Earth Sciences), 106 Pillsbury Hall

Mathematics, 127 Vincent Hall

Mechanical Engineering, 125 Mechanical Engineering

Physics, 148 Tate Laboratory of Physics

Statistics, 270 Vincent Hall

### **Equal Opportunity Statement**

The University of Minnesota is committed to the policy that all persons shall have equal access to its programs, facilities, and employment without regard to race, creed, color, sex, national origin, or handicap. In adhering to this policy, the University abides by the requirements of Title IX of the Education Amendments of 1972, by Section 504 of the Rehabilitation Act of 1973, and by other applicable statutes and regulations relating to equality of opportunity.

Inquiries regarding compliance may be directed to Lillian H. Williams, Director, Office of Equal Opportunity and Affirmative Action, 419 Morrill Hall, 100 Church Street S.E., University of Minnesota, Minneapolis, Minnesota 55455, (612) 373-7969, or to the Director of the Office of Civil Rights, Department of Health, Education, and Welfare, 330 Independence Avenue S.W., Washington, D.C. 20201.

## How to Use This Bulletin

This bulletin describes Institute of Technology programs, learning opportunities, procedures, degree and other requirements, and courses.

The *Class Schedule*, distributed with registration materials just before the registration period each quarter, lists course offerings with prerequisites, class hours, rooms, and instructors. Its closing pages include registration instructions, final exam schedules, and other useful information.

All students and prospective students should also refer to the *General Information Bulletin*. Information about evening courses and summer school offerings is contained in the *Extension Classes Bulletin* and the *Summer Session Bulletin*, respectively.

**Official Daily Bulletin**—This *Minnesota Daily* column publishes announcements about University courses, study opportunities, meetings, and activities. Students are expected to be aware of any information printed in the column that affects them.

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**Institute of Technology students are responsible for all information contained in this bulletin that is pertinent to undergraduate study and to their particular field of study.**

To New IT Students . . .

*The Institute of Technology offers programs of study in the physical sciences and technology. It includes the departments of Aerospace Engineering and Mechanics, Agricultural Engineering, Architecture and Landscape Architecture, Chemical Engineering and Materials Science, Chemistry, Civil and Mineral Engineering, Computer Science, Electrical Engineering, Geology and Geophysics (Earth Sciences), Mathematics, Mechanical Engineering, and Physics and Astronomy.*

*The 350 members of the IT faculty are energetic and dedicated to both education and the development of new knowledge. I hope that each of you will seek out and get to know members of the institute's faculty. You will find that they are, on the one hand, leaders in their professional fields and, on the other hand, concerned with the welfare of students and sensitive to the difficulties of pursuing an education. While I recognize that, under the pressure of studying and attending classes, you may feel that faculty members are somehow remote or inaccessible, I assure you that they are not. Any apparent barrier is easily overcome by taking the initiative to meet individual faculty members and talk to them about your interests, dreams, or needs.*

*We hope that your studies of science and technology in IT will be rewarding. Our programs are designed to prepare you to participate in and contribute to society. We hope that your studies will provide you with the means to make more available and less expensive items that satisfy human needs: food, clothing, housing, transportation, health, recreation, communication, energy, and materials. To a large extent, an understanding of science and technology can provide you with access to an all-powerful "genie."*

*Implicit in the development of the genie is competence in a specialized area of study, and we encourage all students to work to their maximum abilities to develop a high level of competence in their chosen fields. Such achievement can provide you with the resources to advance the quality of society.*

*Because any social or organic system must work in harmony, we encourage students to seek experiences with other students and faculty members, as well as exposure to studies in other colleges. We hope our students will acquire an appreciation for and a balanced view of the totality of society, as well as a fine technical education. We are concerned, then, not only about the development of the genie but also with who controls the genie.*

*As science and technology provide instruments to improve society, they free it progressively from its servitudes and provide more opportunity for personal development. Through their studies, IT students can acquire the tools to contribute to these goals.*

*I hope each of you will be enriched by your classroom experiences and your contacts with our outstanding faculty. We look forward to helping you in your quest for development.*

Roger W. Staehle, dean

# Institute of Technology

## I. GENERAL INFORMATION

### Degrees Offered

The Institute of Technology awards both undergraduate and graduate degrees.

**Undergraduate Degrees**—Bachelor's degrees are offered in architecture and landscape architecture, various branches of science, and major engineering fields. The specific degrees offered are:

- Bachelor of Architecture
- Bachelor of Environmental Design
- Bachelor of Landscape Architecture
- Bachelor of Astrophysics
- 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 Statistics
- Bachelor of Aerospace Engineering and Mechanics
- Bachelor of Agricultural Engineering
- Bachelor of Chemical 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

**Graduate Degrees**—IT and the Graduate School jointly offer a program leading to the master of engineering (M.E.) degree in any of the engineering disciplines. This program provides advanced preparation in specialized design work for recent graduates in engineering as well as for working engineers who wish to improve their technical capabilities.

The objectives of the M.E. program are very different from those of the research-oriented M.S. program. Design study leading to the M.E. degree focuses upon applying knowledge of engineering, physical, and social sciences to adapt materials and sources of power for human uses.

The curriculum, which requires one calendar year to complete, includes up to six courses of a design nature plus several courses in a minor field (related to the student's undergraduate specialty) such as business, economics, statistics, geography, or political science. In addition, students complete a design project that requires the equivalent of 4 or 5 months of work under faculty supervision and often with the assistance of a working engineer.

Applicants are evaluated according to the following criteria:

- Interest in and aptitude for creative, design-oriented programs, as demonstrated by performance in relevant undergraduate courses.
- Industrial design work, including technical reports and reports on undergraduate projects.

## General Information

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—Undergraduate grade point average; a GPA of 2.50 or better is required, and greatest consideration is given to upper division work.

Students who do not meet the above criteria may also be considered upon recommendations from faculty members or practicing engineers. Prospective students should contact the departmental office in their area of specialization for more information and necessary forms.

Each IT department also offers M.S. and Ph.D. degree programs in a number of areas within its discipline. For detailed information about the various graduate programs, consult the *Graduate School Bulletin*.

## Special Programs

**Interdisciplinary Programs**—Any IT student may plan an interdisciplinary program tailored to his or her specific interests. Although a degree is conferred by a single department, students may combine course work from several departments. A few examples of such programs are presented below:

*Acoustics*—Noise and its sources, abatement, and environmental impact are considered.

*Bioengineering*—Study in biology, physiology, and chemistry as well as related engineering courses and project work provide background for this field.

*Business Minor*—Qualified students, after having earned the bachelor's degree in engineering and having completed electives in such areas as accounting, economics, and management, may enter the Graduate School of Business Administration to earn the master's degree in business administration.

*Environmental Engineering*—Topics such as air and noise pollution, solid waste disposal, water resources and quality, and environmental design are studied.

*Nuclear Engineering*—This field combines upper division course work in mechanical engineering, chemical engineering, and physics.

*Transportation*—Project work includes system planning, vehicle design, personalized rapid transit, community impact studies, and other related problems.

Numerous other interdisciplinary programs are possible. Students should contact their departmental office or visit 105 Lind Hall for more information.

**Engineering Internships**—Applied engineering training in selected industries is available during quarters of work experience that alternate with quarters of University studies. Students are registered and considered to be in full-time attendance during the work periods. Internships are usually designated for the last 2 years of study. Application for an internship program must be made before January 1 of the sophomore year. Students should contact their departmental office for more information.

**Premedical Programs**—Because there is no prescribed premedical major, some students plan their IT programs as preparation for medical school. The three Minnesota medical schools, at Duluth, Minneapolis, and Rochester, give strong preference to applicants who are state residents.

The Admissions Committee for the Minneapolis campus Medical School has approved the following courses to fulfill its premedical requirements:

Biol 1011 plus 5 cr in biology, zoology, or genetics (10 cr)

Chem 1004-1005 or 1031-1032, 3100, 3101, 3301, 3302 or 1034, 3034, 3201, 5126 (25 cr)

Engl 1001-1002, Comm 1001-1002, literature, or humanities (12 cr)

Math 1211-1221—mathematics through calculus (10 cr)

Phys 1104-1105-1106-1107-1108-1109, or 1271-1275-1281-1285-1291-1295 (15 cr)

At least 27 cr, evaluated on A-N grading, in humanities, social science, foreign language, or other liberal arts areas (literature and humanities recommended)

Students considering career work in medical research or academic medicine should complete additional electives in these fields beyond the basic requirements listed above. Although reading knowledge of a foreign language is not an admission requirement, it is recommended for students interested in medical research or postdoctoral study in medicine.

Following is a list of faculty members who will assist students in planning premedical programs in the IT departments identified and in applying to medical schools:

Prof. P. Blackshear, Jr. (313 Mechanical Engineering): Mechanical Engineering  
Prof. R. Hobbie (233 Physics): Computer Science, Geology, Geophysics, Mathematics, Physics

Prof. K. Keller (151 Chemical Engineering): Chemical Engineering, Chemistry  
Prof. T. A. Wilson (107 Aeronautical Engineering): Aeronautics, Agricultural Engineering, Architecture, Civil Engineering

The Pre-Health Science Library, 30 Johnston Hall, contains bulletins for all U.S. and Canadian medical schools as well as career information about medical and paramedical fields.

For details about application procedures, students should consult the premedical adviser of their IT department.

**Project Technology Power**—In technical professions such as engineering, representation of blacks, American Indians, and Chicanos is far below that in the population as a whole. In order to help correct this imbalance, IT is committed to increasing the number of black, American Indian, and Chicano students in its programs through recruitment and retention programs that are collectively grouped under the title Project Technology Power. Assistance for IT students served by this program includes Merit Scholarships (eligibility extends to residents of Minnesota, Wisconsin, South Dakota, and North Dakota), dormitory residence scholarships, special tutoring instruction, and, when possible, part-time employment in a technological organization. The project also runs motivational programs for minority students in the eighth, ninth, tenth, and eleventh grades in city schools, and IT students and faculty members are encouraged to participate in these programs.

The Project Technology Power office is located in 3 Lind Hall (373-2673).

**Reserve Officers' Training Corps**—Qualified men and women students may combine work toward an IT degree with participation in an ROTC program. The departments of Military Science (Army ROTC), Naval Science (Navy/Marine ROTC), and Aerospace Studies (Air Force ROTC) each offer 2- and 4-year programs. Participating students earn elective credits, and those who complete one of the training programs qualify for a commission as an officer in one of the four military services. The ROTC curricula are designed to provide instruction and practice in leadership skills as well as in military subjects. Scholarships providing up to 4 years of subsidized education are available also.

Students interested in the specific qualifications, curriculum, benefits, and obligations of each ROTC program should consult the *Army, Navy, Air Force ROTC Bulletin*. Inquiries may also be made at the following offices in the University Armory on the Minneapolis campus: Military Science, room 108, telephone (612) 373-2212; Naval Science, room 203, telephone (612) 373-2230; and Aerospace Studies, room 3, telephone (612) 373-2205.

### Computer Facilities

Digital computers have become common working tools for most people in the areas of science and technology. In recognition of this fact, the Institute of Technology, in cooperation with University Computer Services, has established a number of laboratories for student use. The laboratories are of two types. The time-sharing laboratories allow interactive computing, using a terminal to communicate with a central time-sharing computer system. The batch laboratories allow the student to submit a punched card deck containing a program and data, which is transmitted to a general purpose batch computer. After the program has been run, the output is returned and printed on a line printer at the laboratory where the job was submitted. Facilities in both types of laboratories are available to IT students at any time during the working day, and during evening and weekend hours when demand warrants. The facilities of these laboratories are used 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 tabletop units for data reduction in laboratories to larger models reserved for special projects in computer science 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 that may be entered at different levels is offered by the Department of Computer Science for students in the freshman year, both for those with an elementary background and those who have no prior training. These courses are designed to teach the student a more sophisticated level of programming, using both the interactive and batch systems, and to introduce other languages such as FORTRAN, PASCAL, Assembly Language, and SNOBOL. Thus all students should be 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 are used for a number of applications. Each engineering department in IT has one or more analog computers for instructional use, in addition to those reserved for research projects.

The University Computer Center (UCC) has a variety of advanced computing equipment available to students. The primary batch processing equipment consists of a CDC Cyber 74 and 172 system with approximately 400,000 60-bit words of core storage. Interactive computing is available by means of a time-shared CDC 6400. Both systems are accessible through remote terminals.

A laboratory operated by the UCC is engaged in microprogramming experimentation, microcomputer system development, and image processing. The laboratory contains a PDP-11/40 with a writable control store, several Terak microcomputer systems that have PASCAL, FORTRAN, and BASIC processors, and Dicomed high-resolution digitizers and film recorders. The laboratory is staffed by graduate and undergraduate students, and the equipment is available for use by students.

The Department of Computer Science also operates a computer systems laboratory. This facility includes a PDP-11/40 minicomputer with disk and floppy disk storage and a wide range of asynchronous, synchronous, and parallel communication interfaces. It is currently running the UNIX time-shared operating system. The facilities of the computer systems laboratory are available to all graduate students in computer science.

University Computer Services also administers a special Interactive Computation Laboratory. While there are a number of applications of the equipment of this laboratory of interest to undergraduates, perhaps the most important are in the fields of computer graphics and microprogramming.

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. A major objective of IT is to ensure that all of its graduates have experience with different computers during their undergraduate education so they will be thoroughly familiar with their use on the job.

## Admission Information

**Advising**—Any student who wants to discuss his or her individual admission situation can arrange an interview through the Office of the Assistant Dean, 105 Lind Hall. Students should bring transcripts of high school and college work, test results, and any other pertinent information to the interview.

**Admission as a Freshman**—In order to be admitted as a freshman to IT, the student must complete courses in high school mathematics, including beginning and intermediate algebra, geometry of two and three dimensions, and trigonometry. Physics and chemistry are highly recommended also.

In addition, admission to IT is based on high school rank and a combination of either the mathematics and natural science scores on the American College Testing Program (ACT) examination, the mathematics score on the Preliminary Scholastic Aptitude Test (PSAT), or the mathematics score on the Scholastic Aptitude Test (SAT).

**Admission Without a Designated Major**—Students undecided about a specific major in engineering or science should indicate "IT unclassified" on the application for admission. They are assigned a faculty adviser in the central advising office, 104 Lind Hall. Students may remain in this category for 3 quarters. Permission to continue for a fourth quarter must be requested by petition.

During the period in which students remain unclassified they are encouraged to take advantage of the many special programs that provide information about career opportunities in the various fields in IT. These programs are designed to help students choose a major.

IT unclassified students follow the same first-year academic program as that followed by IT students with a declared major. (A listing of the requirements common to all IT basic lower division curricula is found in section III of this bulletin.)

**Admission With Advanced Standing**—Students transferring from another accredited college or university may enter IT with advanced standing—that is, with credits earned for appropriate courses satisfactorily completed elsewhere. However, students with less than 1 year of college work must meet regular freshman admission requirements.

There are some restrictions on the acceptance of transfer credits by IT. Credits for a sequential technical course in which a student has earned a grade of D will be accepted for transfer only if the student earns a higher grade in the next course in the sequence. Credits for courses transferred from the General College are accepted only by petition; accepted credits may be applied to graduation requirements, but will not be used in the computation of the grade point average or of honor points.

Transfer students should apply and submit transcripts to the Office of Admissions more than a month before the beginning of the quarter they wish to enter. July 15 is the deadline for fall quarter. Transcripts must include all college work attempted, whether satisfactorily completed or not, all extension and independent study course work, as well as any previous course work at the University of Minnesota.

**Admission as an Adult Special Student**—Persons interested in completing individual courses or groups of courses to meet their own needs, rather than in pursuing

## General Information

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a degree program, may be admitted as adult special students to individual IT departments. Applicants are usually required to have a bachelor's degree. Although adult special students are not considered degree candidates, they may subsequently begin degree work when recommended by the department in which they have studied. In such cases, credit earned as an adult special student is accepted as degree credit when appropriate.

Students seeking adult special admission should apply and submit transcripts of all college work to the *Office of Admissions* well in advance of the quarter they wish to begin. Restrictions on admission of nonresident undergraduate students apply also to adult special students. Once accepted, adult special students complete a 1-year plan with a departmental adviser.

**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. Those interested in beginning their studies in the fall quarter apply during the preceding winter or spring. A student admitted under this plan normally does not receive a high school diploma.

**For More Information**—Admission criteria and information about University-wide application procedures are detailed in the *General Information Bulletin*. Students should consult that bulletin in their school's counseling office, or they may request their own copy in person from the information booth in Williamson Hall or by phone or mail from the Office of Registration and Student Records, 110 Williamson Hall, 231 Pillsbury Drive S.E., University of Minnesota, Minneapolis, Minnesota 55455 (telephone 373-2153).

## Financial Aids

The University offers three general types of financial aid to undergraduates: scholarships and grants, student loans, and college work-study. A student employment service is also available. These programs are fully described in the *General Information Bulletin*. Students should consult this bulletin in their high school counseling office or the staff in the Office of Student Financial Aid, 107 Army.

Various IT research facilities offer part-time research and other job opportunities for qualified undergraduate and graduate students. Because a complete listing of facilities and positions is not possible, students should contact individual departments for more information.

Scholarships restricted to IT students are listed below. Some are open to all IT students, and some are open to students in specific IT departments. Unless otherwise noted, one award is made each year. Students should read the Official Daily Bulletin column in the *Minnesota Daily* the first week of winter quarter each year for application information. Applications received by March 1 are given priority consideration.

## Awards and Scholarships

### ALL-COLLEGE

*Alcoa Foundation Scholarships*: For engineering undergraduates who have shown exceptional promise. Preference given to students majoring in electrical, mechanical, and chemical engineering. Three \$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). Three \$750 awards annually.

*J. Miller Brown Scholarship*: Awarded annually to one of the five top students of the freshman class based upon merit and without regard to financial need. Amount is tuition for 1 quarter.

- IT Alumni Association Scholarship:* For undergraduates in any department of the Institute of Technology. Amount is \$200-400.
- Minneapolis Honeywell Award in Engineering and Science:* For distinguished performance of third- and fourth-year students in engineering and science. Amount is \$250-300.
- Minnegasco Engineering Scholarship:* To aid and encourage students in engineering, especially chemical and mechanical. Qualified transfer students and students with advanced standing are eligible.
- Otto John Pfeifer Scholarship:* For an IT student who has completed at least 1 year in engineering studies.
- Harlow C. Richardson Scholarship:* For undergraduates in the Institute of Technology who have demonstrated interest in the humanities. Six or more awards annually.
- Sigma Xi Scholarship (Minnesota Chapter, University of Minnesota):* For an undergraduate with aptitude and proficiency in some field of scientific endeavor. Amount is \$500.
- Sundstrand Foundation Scholarship Fund:* For students in mechanical, electrical, metallurgical, and industrial engineering. A scholarship awarded to a freshman may be renewable for 3 additional years.
- Nellie S. Trufant Memorial Scholarship in Engineering:* For any qualified student in the Institute of Technology in his or her third or fourth year.
- Twin Lakes Auxiliary of the M.S.P.E. Scholarship Fund:* An initial gift of \$150 from the Twin Lakes Auxiliary of the Minnesota Society of Professional Engineers established a scholarship fund to provide assistance to a promising engineering student, with preference given to women.

### DEPARTMENTAL

#### 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:* For 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 or space instrumentation. Award is \$400.

#### Agricultural Engineering

- William Boss Agricultural Engineering Scholarship (Specialty Manufacturing Company, St. Paul):* For an entering freshman in agricultural engineering. Amount is \$500.
- Farmhand Agricultural Engineering Scholarship:* For an entering freshman or undergraduate in agricultural engineering. Amount is \$300.
- Minnesota Concrete Drain Tile Manufacturers' Association Scholarship:* For a student in agricultural engineering or mechanized agriculture, with preference given to freshmen. Amount is \$300.
- Northern States Power Company Agricultural Engineering Scholarship:* For an 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 by the College of Agriculture Scholarship Committee.

#### Architecture

- American Institute of Architects and American Institute of Architects Foundation, Inc., Scholarship Program:* For undergraduate and graduate students in architecture.
- Flour City Architectural Education Fund (Flour City Architectural Metals Division, Hupp Corporation, Minneapolis):* For educational programs and scholarship aid for architecture students. Amount varies.
- Horty, Elving Architectural Fund:* For educational programs and scholarship aid for architecture students. Amount varies.
- Roy Childs Jones Architectural Education Fund:* For educational programs and scholarship aid for architecture students. Amount varies.
- Minneapolis Gas Company Total Energy Fund:* For student who designs, in competition with other students, the best project that would be heated, cooled, and powered via gas total energy.
- Minnesota Society of Architects Scholarship Fund:* For educational programs and scholarship aid for architecture students. Amount varies.
- Ochs Brick and Tile Company Prize in Architecture:* For educational programs and scholarship aid for architecture students. Amount varies.

## General Information

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*Betty Poole Architectural Education Fund:* For educational programs and scholarship aid to students enrolled in the School of Architecture and Landscape Architecture who show exceptional creative ability and have financial need. Amount varies.

*Ralph Rapson F. A. I. A. and Associates Architectural Education Fund:* To aid deserving students with architectural ability, talent, and promise to carry on their professional studies, and to aid and contribute to the educational programs of the School of Architecture and Landscape Architecture. Amount varies.

*Rhodes Robertson Educational Fund in Architecture:* For educational programs and scholarship aid for architecture students. Amount varies.

## Chemical Engineering and Materials Science

*American Institute of Chemical Engineers Loan Fund:* For a chemical engineering student who is active in the A.I.Ch.E.

*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.

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

*Pillsbury Scholarship:* For one junior and one senior in chemical engineering. Amount is \$500 each.

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

## Chemistry

*Peteris Auzins Scholarship:* For a promising physics or chemistry student.

*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.

*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

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

## Civil Engineering

*Minnesota Surveyors and Engineers Society Highway Engineering Scholarships:* For undergraduates in civil engineering with emphasis on highway engineering. Students must be enrolled in the Institute of Technology. Students may apply to Personnel Office, State Highway Department, for summer employment. Amount is \$400-600.

*Adolph A. Sommerfeld Scholarship Fund in Civil Engineering:* For students in civil engineering. Awarded on the basis of academic ability, professional promise, and financial need.

## Electrical Engineering

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

## Geology and Geophysics

*American Metal Climax Foundation Fund:* For fieldwork.

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

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

*William A. King Fund:* To assist undergraduate students in meeting the expenses of field camp or field-related studies.

*Longyear Fellowship:* Given in alternate years to undergraduate students.

## Mathematics

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

*John Torrence Tate Memorial Scholarship:* See description under Chemistry scholarships.

## Mechanical Engineering

*American Institute of Industrial Engineers, Twin Cities Chapter, Scholastic Award:* For a sophomore or junior mechanical engineering student who is pursuing an industrial engineering option and who is a member of the student chapter of A.I.I.E.

*Filtration Society Scholarship, North Central Chapter:* For a senior or graduate student in mechanical engineering in the field of particle technology. Contact the department for details.

*Pillsbury Company Scholarships:* See description under Electrical Engineering scholarships.

*Rosemount Engineering Company Instrumentation Award:* See description under Aerospace Engineering and Mechanics scholarships.

## Mineral Resources and Geo-Engineering

*M. A. Hanna Company Scholarships:* For Hanna Company employees, their sons and daughters, or their relatives who wish to attend the University on the Minneapolis or Duluth campuses, or the Michigan College of Technology, Houghton, Michigan. Preference is given to those enrolled in mineral technology (mineral and metallurgical engineering), but other students in IT may also be eligible. Amount is \$750. Entering students apply through their high school by January 1 each year; University students follow regular procedure. Two awards each year, renewable if the student maintains at least a 3.00 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 includes the Cleveland-Cliffs Iron Company Fund, E. J. Longyear Memorial, and Mesabi Tire Co., Inc., Scholarship.

## Physics

*John Torrence Tate Memorial Scholarship:* See description under Chemistry scholarships.

## Student Services

**Faculty Advisers**—At the time of registration, each new IT student is assigned a faculty adviser from her or his major department. During fall quarter, students consult with their adviser to plan their schedule for the rest of the year. During spring quarter, students meet again with their adviser to plan a program of studies for the following year. All students must have their adviser's approval of their program before they are allowed to register, as well as for any changes after registering. Students who wish to change advisers within the same department should go to their departmental office.

**Professional Counselors**—Counselors are available to discuss questions about IT, choice of major, career plans, or any personal problems students may have. Counseling appointments are scheduled in 105 Lind Hall.

**Undergraduate Teaching Assistants**—To help all students perform to the best of their abilities, IT provides peer tutorial assistance for its students in chemistry, mathematics, physics, and other IT courses. These teaching assistants are selected from junior and senior IT honor students who are willing and able to work with other students. Tutoring assistance is provided in various locations—on campus, in residence halls, and at selected metropolitan high schools.

Teaching assistants are available during scheduled office hours Monday through Friday in 3 Lind Hall. They hold regularly scheduled hours, usually from 7 p.m. to 10 p.m. Sunday through Thursday, in Comstock, Frontier, Territorial, Middlebrook, Sanford, and Bailey halls.

Teaching assistants staff several metropolitan high schools, including Edina South View Junior High, Minneapolis Washburn, Mounds View, Robbinsdale Junior High, St. Paul Johnson, and West St. Paul Henry Sibley. The schedule at these locations is usually 7 p.m. to 9 p.m. on Tuesday and Wednesday.

In addition, graduate teaching assistants staff designated study rooms in the departments of Chemistry, Computer Science, Mathematics, and Physics. These

## General Information

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teaching assistants offer help with course work taught by the department with which they are associated and are available during scheduled hours, usually 9 a.m. to 4 p.m.

Inquiries about tutorial programs should be made to the director of lower division programs, 104 Lind Hall.

**IT Career Planning and Placement**—The IT Career Planning and Placement Office, located in 15 Experimental Engineering, has personnel available to assist graduating seniors, advanced degree candidates, and alumni in career choices and career development.

A wide variety of companies, representing local, state, and national organizations, visits the Career Planning and Placement Office each year. The office schedules interviews and maintains a library with information about companies and government agencies that are prospective employers. Assistance is also available to undergraduate and graduate students seeking summer employment.

The office maintains a résumé file for alumni and publishes a monthly newsletter listing positions available for experienced personnel.

A course is taught each fall quarter for students needing assistance in career decision making. The course, I of T 1222, Introduction to Careers in Science and Engineering, 1 or 2 credits, is open to all students.

The Career Planning and Placement Office also coordinates and supplies information about and applications for the Engineer In Training (EIT) examinations.

## Student Activities

Architects, scientists, and engineers find that membership in technical or professional societies usually helps their career development. Many of these societies have student chapters at the University. Through them students have 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.

**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. Additional professional societies include 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 IT promote the high standards of the engineering profession by conferring memberships, awards, and other honors on undergraduates distinguished for scholastic achievement and for character. These fraternities normally elect members from the junior and senior classes on the basis of scholarship, as measured by class rank, and character, as judged by peers and faculty members. 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 a single department: Alpha Epsilon (Agricultural Engineering), 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).

**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) during spring quarter. 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 composed of students and faculty members.

**IT Student Board**—The IT Student Board is the executive body of the students in the Institute of Technology. The board represents the students in matters affecting the general interests of the institute and the University. The Student Board is responsible for general supervision of Engineers' Day (IT Week) and other student activities in the Institute of Technology.

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

## Professional Registration

Registration as an engineer is a legal requirement for certain kinds of practice. A professional license is required before an individual may use the designation of engineer in any legal connection. There is an increasing interest in industry for engineers to be registered as an indication of professional competency, even though they have no legal obligation to do so. Many engineers have obtained a license to show their support for the concept of a legal recognition of the professional standing of the engineer. Many also obtain a license because professional registration may be useful or required in future employment.

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 specified number of years of appropriate experience. The examination 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 obtained from:

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

## Continuing Education

Scientists and engineers frequently find the need to enhance their professional competence in response to technological change and the proliferation of newly reported research data. Others who change their professional interests in midcareer find the need to acquire training in areas different from those of their undergraduate specializations. In addition to on-the-job experience, technical reading, and attending professional meetings, continuing education studies offered by the University of Minnesota can help individuals accomplish these goals.

## General Information

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Because of the growing interest in postgraduate course work, IT and Continuing Education and Extension created the Office of Continuing Education in Engineering and Science. This office surveys the needs of technical specialists and responds by arranging quarter-length courses, special conferences, and workshops.

The office also maintains an Engineers Information Registry, which lists the names of professionals, their companies, job classifications, and areas of interest. This registry, along with input from advisory committees, companies, and professional societies, is used to determine areas of interest shared by practicing engineers and scientists. It also aids in identifying locations outside the metropolitan area where courses could be offered for the convenience of those enrolled.

**Professional Development Recognition Program (PDRP)**—This program, offered jointly by the Institute of Technology and Continuing Education and Extension, offers a personalized, flexible plan for the continuing professional development of the degree holding engineer or scientist. Participants prepare a statement of their specific educational objectives and then meet with an IT faculty member to plan a program that will meet these goals.

The minimum number of credits required to complete a PDRP is 18. Up to 50 percent of this total may be satisfied through non-University work such as in-plant company programs and conferences and seminars offered by other recognized institutions.

With an average expenditure of 10 hours per week, a PDRP normally requires two calendar years to complete. Upon completion of the program requirements, participants receive a citation that states their self-chosen objectives and the steps taken to achieve them.

**UNITE Instructional Television**—Approximatey 20 courses each quarter are offered through UNITE (University-Industry Television for Education), an instructional television system for continuing education at the employee's worksite. These include both upper division and graduate courses as well as specially developed courses and seminars. Classes are held in specially equipped studio classrooms with on-campus students in attendance. The system is interactive, enabling students at all sites to talk with the instructor and to take part in class discussions. Participating companies help support the system through payment of a special fee based on the number of credits for which its employees are enrolled. This fee is separate from tuition, which is paid either by the student or the company, depending upon company policy. The growing list of organizations offering UNITE courses to their employees includes the Donaldson Company, FluidDyne, Honeywell, Inc., IBM Corporation, 3M Company, Northern States Power Company, Sperry Univac Defense Systems, Sperry Univac-Roseville, U.S. Bureau of Mines, and Physical Electronics, Inc.

Further information about continuing education opportunities for engineers and scientists may be obtained from the Director, Continuing Education in Engineering and Science, 320/322 Aerospace Engineering, 110 Union Street S.E., University of Minnesota, Minneapolis, Minnesota 55455; telephone (612) 373-3132.

## II. ACADEMIC POLICIES AND PROCEDURES

### Grading

**Grading System and Grade Point Average**—The Institute of Technology uses the same grading and symbol system as the other collegiate units on the Twin Cities campus. Students should consult the *Class Schedule* for an explanation of the system.

Only credits taken on the A-N grading system are calculated in the grade point average. A 2.00 average or better is considered satisfactory work. Each letter grade carries the following grade points per credit: A=4.00, B=3.00, C=2.00, and D=1.00. The grade point average is determined by dividing the sum of the grade points by the sum of the credits.

The N grade is assigned when a student does not earn an S or a D or higher and is not assigned an I. It stands for no credit and carries no grade points.

**S-N Grading**—An IT student can elect the S-N grading option for any course offered on an S-N basis except those specifically designated by the student's major department to be taken on an A-N basis only. Each department has available a list of those courses or categories of courses that it restricts to A-N registration for its majors.

New students in the Institute of Technology may take only one course on S-N during their first quarter in residence (in addition to any course available only S-N).

An IT student may take no more than two courses per quarter or one course per summer session on S-N.

No more than 25 percent of the total University of Minnesota residence credits presented for graduation for a given curriculum may be taken on S-N. This regulation does not apply to credits presented in excess of the minimum required.

Assuming that all other requirements and regulations are met, a student may cancel-add from A-N to S-N or from S-N to A-N through the second week of a quarter, but not thereafter.

S-N registration is indicated by inserting the number of course credits in the S-N column on the registration card. Change from or to S-N registration in a given course must be made on a cancel-add form.

**Incompletes**—The I grade is assigned when a student has completed all but a small portion of the work of a course and has made prior arrangements with the instructor to make up the work. An incomplete will become an N grade if not made up by the end of the next quarter in residence.

**Withdrawals**—The symbol W indicates official cancellation of a class without grade. IT students may withdraw from a course from the end of the second week of a quarter up through Study Day and receive this symbol, regardless of their academic standing in the class at the time of cancellation. A W received through the end of the sixth week of a quarter is *not* used in calculation of the honor point deficiency.

**Auditing**—The symbol V indicates that the student is a visitor in a course and is taking the course without credit. Courses audited may be taken for a grade and credit at a later time. A student may change from a credit/graded registration to an audit/nongraded registration up to the end of the sixth week of a quarter with the permission of the instructor.

**Continuation Courses**—The symbol X is reported in continuation courses in which a grade is not assigned until the entire sequence is completed. Upon completion of the sequence, a grade is submitted for each X on the record.

## Academic Policies and Procedures

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**Transcripts**—Student academic records are maintained on a computerized transcript system. For a description of the system, see the *General Information Bulletin*.

### Academic Standards

**Continuation in Sequences**—IT students taking the following lower division sequence courses must earn a grade of at least C each quarter to continue in the sequence:

Chem 1004-1005, 3100-3101  
Chem 1031-1032, 1133<sup>1</sup>  
Chem 3301/3305, 3302/3306  
Chem 3331, 3332/3335, 3333/3336  
CSci 1100, 1101  
EE 1510<sup>2</sup>  
Geo 1001, 1002  
Math 1201, 1211-1221-1231<sup>3</sup>  
Math 1311-1321-1331<sup>3</sup>  
Math 1611-1621<sup>3</sup>  
Math 3211<sup>3</sup>  
Math 3511, 3521, 3531  
Math 3611-3621  
Phys 1121-1122  
Phys 1271-1281-1291<sup>4</sup>  
Phys 3511-3512-3513

**Honor Points and Honor Point Deficiency**—The Institute of Technology calculates honor points and an honor point deficiency (HPD), which are used to determine academic progress, as follows:

A=2 per credit  
B=1 per credit  
C=0 per credit  
S=0 per credit  
D= - 1 per credit  
N= - 2 per credit  
W (after sixth week)= - 2 per credit

An I grade is not counted initially. If made up, the new grade will be counted on the basis of the above table. If not made up by the end of the next quarter in residence, the I reverts to an N, and that grade carries a deficiency of 2 per credit.

Withdrawals after the end of the sixth week of a quarter are considered in the honor point deficiency calculation; the W is treated as an N in such cases.

**Quarterly Honor Point Deficiency**—A student will be placed on probation when the honor points earned for a given quarter fall in the negative range. If the honor point deficiency is 10 or more, the student may not again register in the Institute of Technology without the permission of the Scholastic Standards Committee of his or her major department.

<sup>1</sup>For continuation in the chemistry major sequence (Chem 3331) an IT student must have earned a C in Chem 1133.

<sup>2</sup>A C grade or better in EE 1510 is required for admission to EE 3010.

<sup>3</sup>In order to continue in additional mathematics courses (in particular Math 3211 or Math 3221) or sequences an IT student must earn at least a C grade in Math 1231 or Math 1331 or Math 1621. A student must earn at least a C grade in Math 3211 before taking Math 3231.

<sup>4</sup>For continuation in physics sequences, an IT student must earn at least a C grade in Phys 1291.

To obtain a decision on continuance, a student must complete an E-100 form (available in 105 Lind Hall) and must appear in person before the departmental Scholastic Standards Committee. The departmental committees normally meet only between quarters. This means a student with an HPD of 10 or more at the end of the fall quarter, for example, will be allowed to register for spring quarter classes only after his or her committee meets at the end of winter quarter and only if continuance is granted.

A student who is allowed to continue will normally be required to complete specified goals for the next quarter in residence, and these will be indicated on the E-100 form. If the goals are met, the student will be automatically "continued" at the end of the quarter. If the goals are not met, the student will be routinely dropped. A continued student will not be allowed to register for a future quarter unless his or her goals are met.

**Cumulative Honor Point Deficiency**—An IT student will not be allowed to again register in the Institute of Technology if her or his cumulative honor point deficiency is equal to or greater than 15, unless granted a continuance by the departmental Scholastic Standards Committee. The cumulative calculation includes all work taken at the University of Minnesota beginning in fall quarter 1975. The student with an unsatisfactory cumulative HPD must appear before the Scholastic Standards Committee of his or her major department with an E-100 form. It is the responsibility of the committee to decide whether to continue or to drop the student.

**Drop Status**—A dropped student may not reenter day school classes or take IT evening classes through Continuing Education and Extension unless granted permission by the departmental Scholastic Standards Committee.

**Repeating Courses**—Students are allowed to repeat courses in which they received a grade of D, and only the last grade earned is then used in computing their grade point average and honor point deficiency.

Students who want to repeat courses in which they received a grade of C or better must petition for approval to do so. Forms are available in 105 Lind Hall.

Students who repeat a required course three times and do not earn a grade of C or higher will be subject to drop action by their departmental Scholastic Standards Committee.

**ROTC Courses**—Grades received in all ROTC courses will be entered on the student's transcript and will be counted in the grade point average and honor point deficiency calculations.

ROTC credits may be used to satisfy CLE requirements for those courses that have been certified as suitable for category 2 (The Individual and Society) by the appropriate academic department of the University.

**Changing Majors**—To change majors within IT, students must petition requesting such a change. Forms are available in 105 Lind Hall. Petitions must be approved by the chair (or representative) of the department to which the student is transferring.

To change majors from IT to another collegiate unit or campus within the University, students must apply for transfer through the Office of Admissions and Records, as far as possible in advance of the projected transfer. Some units have transfer application deadlines. Students must meet admission requirements of the unit they plan to enter.

**Residency Requirement**—A student earning a bachelor's degree must complete 45 credits after admission to IT, of which at least 30 credits must be completed in the senior year.

## Academic Policies and Procedures

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**Dean's List**—To qualify for the quarterly Dean's List, a student must complete a minimum of 12 credits with a grade point average of 3.50 or better. The credits may all be completed on A-N grading or on a combination of A-N and S-N grading.

**Graduation**—The bachelor's degree with professional designation will be recommended for students who earn a grade point average of 2.00 or better, with no cumulative honor point deficiency, and who have completed all of the required work and the total number of credits specified for their curriculum. Students should file an Application for Degree at the Registration and Records Office and pay the graduation fee approximately a year prior to graduation.

**Graduation With Honors**—Students with a grade point average of 3.20 or better in their undergraduate work are granted their degree "with distinction." Students with a grade point average of 3.70 or better in their undergraduate work are granted their degree "with high distinction."

Effective spring quarter 1980, a grade point average of 3.50 will be required for graduation with distinction, and a grade point average of 3.80 will be required for graduation with high distinction.

## Conduct and Discipline

The Institute of Technology assumes that all students enroll in its programs with a serious learning purpose, and expects them to be responsible individuals who demand of themselves high standards of honesty and personal conduct.

The Institute of Technology expects the highest standards of honesty and integrity in the academic performance of its students. Any attempt by a student to present work that she or he has not prepared, or to pass an examination by improper means, is regarded by the faculty as a serious offense, which may result in immediate expulsion of the student. Aiding and abetting a student in an act of dishonesty is also considered a serious offense.

IT reserves the right to dismiss at any time a student whom it deems undesirable for any reason. Unethical conduct, wherever it may occur, is considered sufficient grounds for dismissal. Unauthorized use of an instructor's or administrator's name on a University form or other paper is an example of conduct considered grounds for dismissal.

A student has the right to appeal any disciplinary action. Copies of the procedures for appeal are available in 105 Lind Hall upon request.

If a student's infraction involves both IT judicial proceedings and court proceedings, and if an IT decision might prejudice his or her court case, IT will hold its decision in abeyance until the court proceedings have been concluded.

## Access to Student Educational Records

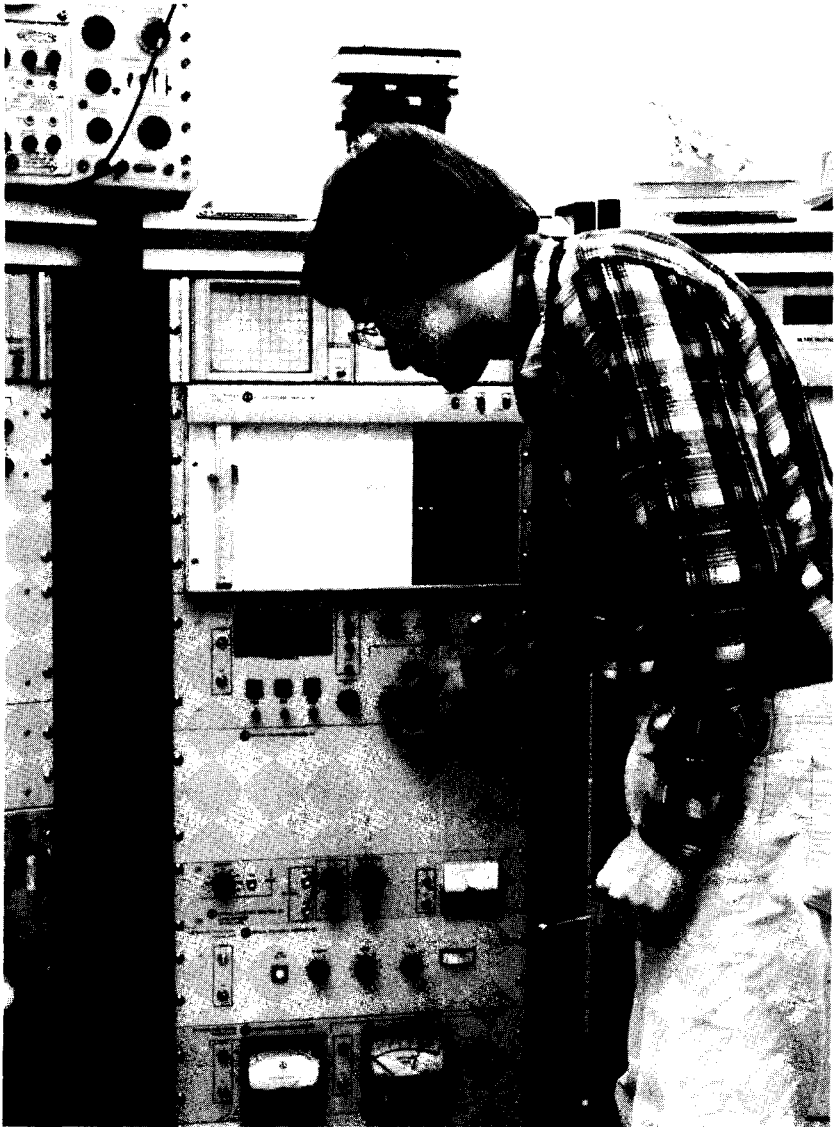
In accordance with regents' policy on access to student records, information about a student generally may not be released to a third party without the student's permission. The policy also permits students to review their educational records and to challenge the contents of those records.

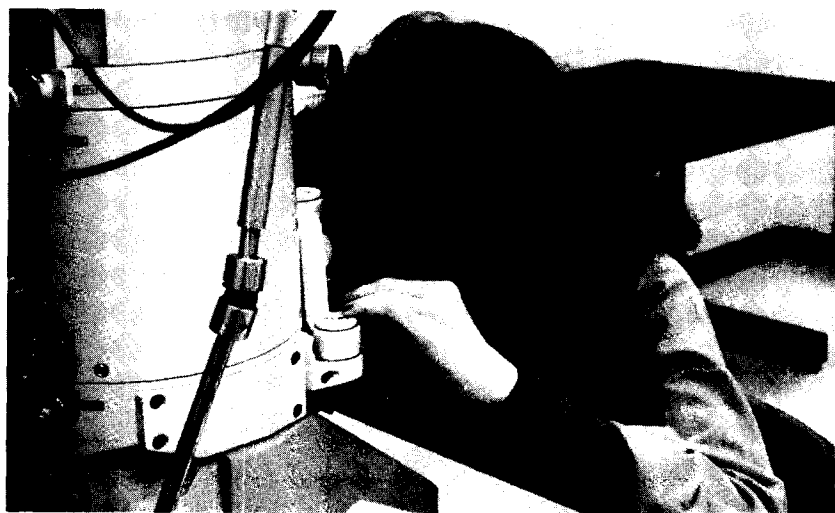
Some student information—name, address, telephone number, dates of attendance, college and class, major, adviser, and degrees earned—is considered public or directory information. To prevent release of such information outside the University while in attendance at the University, a student must notify the records office on his or her campus.

## *Access to Student Educational Records*

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Students are notified annually of their right to review their educational records. The regents' policy, including a directory of student records, is available for review at the information booth in Williamson Hall, Minneapolis campus, and at the records offices on other campuses of the University. Questions may be directed to the Office of the Coordinator of Student Support Services, 260E Williamson Hall, 231 Pillsbury Drive S.E., University of Minnesota, Minneapolis, Minnesota 55455; telephone (612) 373-2106.





### III. CURRICULAR REQUIREMENTS

**Changes**—Academic requirements stated in this bulletin are subject to change at any time upon approval of the faculty. Notification of changes in requirements is distributed to students with their registration materials.

#### Liberal Education Requirements

Institute of Technology students, whatever their area of specialization, are expected to hold in common with all University students the search for a liberal education—one that enhances their powers of judgment and choice. A liberal education implies awareness of the intellectual instruments for acquiring and communicating knowledge, understanding of the ways in which engineers and scientists contribute to our knowledge of ourselves and our 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 by the All-University Council on Liberal Education (CLE). The IT minimum liberal education requirements, together with required courses in English, mathematics, and the physical sciences, exceed the basic all-University requirements of the Council on Liberal Education.

Liberal education course work should be planned to complement the student's subsequent professional studies. Students are encouraged to complete advanced level courses in some areas rather than a large number of unrelated beginning courses. Copies of recommended liberal education elective programs are available in departmental offices, and students are encouraged to consult these programs when choosing their electives.

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

1. Two courses (8-10 credits) of English composition or communication. If a student is exempt from freshman English, the 8-10 credits must be taken in item 3 below.
2. Three courses (12-15 credits) in category 3, The Individual and Society.
  - Afro 1015, 1036, 1441, 1442, 3001-3002-3003, 3061-3062, 3075, 3076, 3081-3082, 3091, 3092, 3098, 5001-5002, 5101, 5102, 5103, 5401
  - AgEc 1020, 3610
  - Amln 1771, 3026, 3036, 3111, 3112, 3121, 3131, 3311
  - AmSt—All courses
  - Anth—All courses except 5161
  - Arch 1001-1002-1003
  - Chic—1105, 1106, 1107, 3112, 3113, 3114, 3116, 3118, 3211, 3212
  - CJS—all courses
  - Cias 1001, 1002, 1003, 1004, 1005, 1006, 1011, 1022, 1033, 1042, 1044, 1055, 1066, 3071, 3072, 3073
  - CPsy—All courses
  - Econ—All courses
  - Fren 3501-3502-3503
  - FSoS—All courses
  - Geog—All courses except 1425
  - Ger 5331
  - Grk 5794
  - Hebr 3131-3132
  - Hist—All courses
  - Hum—All courses
  - Indc 1504-1506, 3506, 3507, 3533, 5511-5512, 5520, 5531-5532-5533
  - Ital 3501-3502
  - Jour 1003, 1701, 3021, 3776, 5501, 5601, 5603, 5611, 5615, 5721, 5801, 5825

## Curricular Requirements

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- Lat 5794
  - LAS 5101
  - Lib 5101, 5221
  - MidE 3005, 3036, 3511, 3512, 3525, 3541, 3542, 3543
  - Phil 1002, 1003, 1004, 3001, 3002, 3003, 3004, 3302, 5003, 5005, 5008, 5021, 5033, 5034, 5035, 5036, 5041, 5042, 5043, 5044, 5054, 5301, 5302, 5311, 5414, 5611, 5612, 5621, 5781
  - Pol—All courses except 3085
  - Psy—All courses
  - RelS 1031-1032-1033
  - Russ 3501, 3502, 3503
  - Scan 1504, 3501
  - Soc—All courses
  - Span 3001, 3002, 3003
  - Spch 3211, 3401, 3402, 3431
  - SSci—All courses
  - SW—All courses
  - UrbS 3101, 3102, 3103
  - WoSt 1005, 1006, 1977, 3300
3. Two courses (8-10 credits) in category 4, Literary and Artistic Expression.
- Afro 1301, 3055, 3057, 3101, 3102, 3105, 3108
  - Amin 3221, 3242, 5214, 5215
  - AmSt—All courses
  - Arab 5211-5212
  - Arch 1021, 1022, 1023, 5051, 5052, 5053, 5054, 5055, 5056
  - ArtH—All courses
  - ArtS—All courses
  - Chic 3507, 3508, 3510, 3511, 3513
  - Clas 3081, 3082, 3083, 5081, 5082, 5083, 5109, 5115
  - Dsgn 1501, 1521, 1541
  - Engl—All courses except Comp 3085
  - Foreign Languages—Any upper division foreign literature course may be used
  - Fren 3601-3602-3603
  - Ger 3104, 3105, 3301, 3302, 3303, 3311, 3312, 3313, 3331, 3341, 3342, 3401, 3601, 3602, 3603
  - Grk 1104-1105, 3106-3107, 3461, 3464, 3471, 3474
  - HE 1501, 1521, 1541
  - Hebr 3201-3202, 3121-3122-3123, 3301
  - Hum—All courses
  - Jour 5606, 5171
  - LA 1021
  - Lat 1104, 3106, 3461, 3462, 3463, 3464, 3465, 3466, 3467, 3471, 3472, 3473, 3474, 3475, 3476
  - MdGk 1104-1105
  - Mus—All courses
  - Pers 5990
  - Phil 3502, 5501, 5512
  - Russ 3601-3602, 5403, 5409
  - Scan 5503, 5512, 5601, 5631, 5632, 5633, 5670
  - Spch 3201, 3202, 3203, 3204, 5204
  - Th—All courses
  - WoSt 3103, 3501, 3502, 3631, 3701
4. Credits necessary to complete the 36-credit requirement. These credits are in addition to those required for each category. The credits may be taken in any of the above categories. They may include courses in the biological sciences and ecology, unless specifically excluded by the student's department. Comp 3085 and courses in astronomy, chemistry, computer science, geology, mathematics, physics, business, accounting, and related courses may not be used to fulfill liberal education requirements. CLEP examinations may be used for partial fulfillment of requirements. Students are strongly urged to take courses that study the impact of science and technology on society and the environment.

*The above-listed courses are examples only and do not include all of the courses that may be used to fulfill the requirements.*

Courses required for a specific major curriculum that also meet the distribution requirements above may be applied toward the IT liberal education requirements.

Students are encouraged to take advanced level courses and deepen their knowledge of some area in which they are interested. The prerequisites for upper division courses are often quite minimal.

Normally, students are expected to fulfill the specific category requirements. However, students who feel that their education is better served by a certain amount of concentration in one category, even when this does not fulfill the letter of the

## First-Year Core Requirements

distribution requirements, may petition to be exempted from the requirements for that category.

**Technology and Society**—Every student in the Institute of Technology should have an appreciation of the role of technology in society in order to make the value judgments she or he must make as a professional and as a citizen. While this appreciation can be gained in many ways, students are encouraged to take suitable course offerings in IT and other University units to accomplish this goal. A list of suitable courses is available from the office of the assistant dean for student affairs and from IT faculty advisers.

**Liberal Education Requirements for Students in Engineering Curricula**—Students in engineering programs must meet the liberal education requirements stated above. They must complete a minimum of 24 credits in the categories The Individual and Society, and Literary and Artistic Expression. These 24 credits cannot include any ROTC designator courses (Air, Mil, Nav) except those certified as suitable by the appropriate academic department of the University, any 1000-level introductory language courses, or any freshman composition courses.

### First-Year Core Requirements

Lower division curricula are similar in many IT departments, because all degree programs require a solid foundation in chemistry, mathematics, and physics. For the benefit of freshmen, transfer students, and students changing majors, the common elements of first-year programs in all IT departments are listed below. IT unclassified students usually follow the program for the department most closely related to their major interest.

Note that students majoring in chemistry, chemical engineering, and metallurgy/materials science, unlike majors in other IT departments, begin chemistry courses their freshman year.

Also, in fulfilling the mathematics requirements, all students have the option of taking either Math 1211-1221-1231 (Analysis I-II-III) or Math 1311-1321-1331 (Computer Calculus I-II-III).

#### CORE 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 I-II-III.....	5	5	5
Comp 1001-1002—Introductory Composition			
(or) Comm 1001-1002—Communication.....	4	4	..
Phys 1271-1281—General Physics.....	..	4	4
Phys 1275-1285—General Physics Laboratory.....	..	1	1
Elective <sup>1</sup> .....	4 or 5	..	4 or 5
	13 or 14	14	14 or 15

#### CORE B

Chemical Engineering, Chemistry, Materials Science

Math 1211-1221-1231—Analysis I-II-III			
(or) Math 1311-1321-1331—Computer Calculus I-II-III.....	5	5	5
Chem 1031-1032, 1133 <sup>2</sup> —General Principles.....	5	5	5
Comp 1001-1002—Introductory Composition			
(or) Comm 1001-1002—Communication.....	4	4	..
Nontechnical Elective.....	..	..	4
	14	14	14

<sup>1</sup>Elective may be in computer science, introduction to engineering, or a nontechnical area.

<sup>2</sup>Chem 1133 is required only for chemistry majors.

## Curricular Requirements

### CORE C

Architecture, Environmental Design

	Credits		
	f	w	s
Math 1211-1221-1231—Analysis I-II-III (or) Math 1311-1321-1331—Computer Analysis I-II-III .....	5	5	5
Comp 1001-1002—Introductory Composition (or) Comm 1001-1002—Communication .....	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	17	17

### CORE D

Landscape Architecture

See department curriculum.

## Major Program Requirements

### Aerospace Engineering and Mechanics

Aerospace engineering is a pioneering field that 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.

Aerospace engineering is a professional field that is constantly changing and that is concerned with 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 provide this broad background. The required technical courses offer a firm basic knowledge of engineering science, aerodynamics, mechanics, and dynamical systems. The elective portion of the curriculum is extremely flexible and allows the student to build on the fundamental work and to concentrate his or her study in an area of special interest. The available options are varied, permitting students to prepare for careers in many different 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 of study. The program operates in conjunction with the intern program of the Department of Mechanical Engineering as a program of the School of Mechanical and Aerospace Engineering. Prospective participants should contact the director of the program for information.

The department is actively involved in transportation studies, and students with an interest in the problems of urban and interurban transportation can participate in a special program in this area. The program includes a carefully selected group of elective courses from various departments designed to 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 problems arising from noise pollution and possible solutions to these problems can select special courses in acoustics, offered by this and other departments, to form a coherent program that emphasizes acoustical engineering.

## Aerospace Engineering and Mechanics

A recommended program for students majoring in aerospace engineering and mechanics is presented below. The suggested lower division courses provide the necessary background for the more advanced upper division courses. The student has a great amount of flexibility in arranging the upper division program.

### LOWER DIVISION

	Credits
Comp 1001, 1002—Introductory Composition	
(or) Comm 1001, 1002, or 1003—Communication	8
Liberal Education Electives	16
Math 1211, 1221, 1231—Analysis I, II, III	
(or) Math 1311, 1321, 1331—Computer Calculus I, II, III	15
Math 3211, 3221—Analysis IV, V	10
Phys 1271, 1281, 1291—General Physics	12
Phys 1275, 1285, 1295—General Physics Laboratory	3
Chem 1014—General Principles	4
EG 1026—Engineering Graphics	2
CSci 1100, 1101—Introduction: FORTRAN Programming	
(or) CSci 3101—Introduction: FORTRAN Programming	4
EE 3000—Circuits	4
ME 3301—Thermodynamics	4
Phys 3501—Modern Physics	4
(or) Biol 1101—General Biology	
(or) EBB 3101—Ecology	
(or) Geol 5601—Limnology	
(or) Physl 3055—Principles of Physiology	
(or) equivalent	
AEM 1001, 1005, 1006—Aerospace Engineering Orientation and Survey	3
AEM 1011—Statics	2
AEM 3016—Deformable Body Mechanics	4
AEM 3036—Dynamics	4
Total Credits	99

### UPPER DIVISION

Liberal Education Electives	12
Required Technical Courses	46
AEM 3401—Introduction: Dynamical Systems (4)	
AEM 5200, 5201, 5202—Fluid Mechanics I, II, III (12)	
AEM 5206—Lifting Surfaces (4)	
AEM 5300—Flight Mechanics (4)	
AEM 5319—Dynamic Stability of Aerospace Craft (4)	
AEM 5515—Aerospace Structures I (4)	
AEM 5642, 5645, 5646—Laboratory I, II (6)	
ME 5342, 3305—Heat Transfer, Propulsion (8)	
Selected Required Technical Courses (select five of the nine listed)	20
AEM 5309—Rocket Performance (4)	
AEM 5321—Automatic Flight Control Systems (4)	
AEM 5330—Design I (4)	
AEM 5435—Introduction: Random Vibrations (4)	
AEM 5438—Intermediate Dynamics (4)	
AEM 5580—Mechanics of Elastic Solids I (4)	
AEM 5650—Aeroelasticity (4)	
AEM 5687—Acoustics (4)	
MatS 3400—Mechanical Properties: Materials (4)	
It is strongly recommended that MatS 3400 be taken either prior to or concurrent with AEM 5515 and AEM 5642.	
Other Required Course	2
Comp 3085—Technical Writing (2)	
Must be taken concurrently with AEM 5645.	
Technical Option	12
Technical electives should be selected from one of several recommended optional programs—see information in the departmental office.	
Electives	6
Total Credits	98

### Agricultural Engineering

Agricultural engineering is the application of engineering principles to food and fiber production and processing, rural living, and management of land and water resources. Agricultural engineers utilize their skills to increase production of crops and livestock, to improve the quality of agricultural products, to reduce the dependence of agriculture on human labor, and to use soil, water, and energy resources wisely. These objectives are accomplished by developing and applying new and improved processes, machines, structures, and systems that achieve economic goals and also give full consideration to human and environmental factors.

Agricultural engineers serve not only the agricultural and food industries but also the general public, through their role in producing food efficiently and in protecting our soil and water resources. They provide an essential link between the science of agriculture, which is largely biological, and engineering, which utilizes physical science to solve everyday problems. As world population outpaces world food production, the work of agricultural engineers becomes more and more important both at home and abroad.

The agricultural engineering curriculum can be completed in 4 years and requires a minimum of 190 credits. Emphasis is on the engineering sciences and on engineering design. A general study of biology, agricultural science, communications, social science, and the humanities is included as well, since the agricultural engineer must be able to communicate and work with a variety of professional people. The program is designed to provide students with a fundamental background for continued professional growth and prepare them to contribute to the needs of an ever-changing society.

Each student, with the assistance of an adviser, plans a curriculum tailored to his or her individual interests. The principal fields of specialization within agricultural engineering are: design of agricultural power and machinery, soil management and water control, building design and environmental control, food engineering, and agricultural waste management. Students select special courses from a number of subject areas to give them a broad background in topics related to their specialization.

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

The first 2 years of the program provide the background necessary to complete the more advanced studies offered in the junior and senior years. They also provide a portion of the general educational experience essential to an engineering education.

#### GENERAL REQUIREMENTS

Mathematics	Credits
Math 1211, 1221, 1231—Analysis I, II, III .....	15
Math 3211, 3221—Analysis IV, Linear Algebra and Differential Equations .....	10
Physical Sciences	
Phys 1271, 1281, 1291—General Physics .....	12
Phys 1275, 1285, 1295—General Physics Laboratory .....	3
Chem 1004, 1005—General Principles (or) Chem 1014—General Principles of Chemistry plus natural science elective .....	8-10
Agricultural and Biological Science	
Electives .....	8
Engineering Science	
EG 1025—Engineering Graphics .....	4
AEM 1015—Statics .....	4

	Credits
AEM 1031—Computations in Agricultural Engineering .....	2
AEM 3016, 3036—Deformable Body Mechanics, Dynamics .....	8
AgEn 3052—Physio-Engineering in Agriculture .....	4
AgEn 3060—Analysis in Agricultural Engineering .....	4
CE 3400—Fluid Mechanics .....	4
EE 3002—Electric Machinery and Power Distribution (or) EE 3000—Circuits .....	4
ME 3301, 5342—Thermodynamics, Heat Transfer .....	8
Electives .....	8
<b>Engineering Design</b>	
AgEn 1071—Introduction to Agricultural Engineering .....	2
AgEn 5081, 5082, 5083, or 5084—Design .....	4
Agricultural Engineering Electives: AgEn 5060, 5070, 5072, 5130, 5140, 5330, 5340, 5540, 5550, 5730, 5740, 5910 .....	16
Approved Engineering Design Elective .....	4
<b>English Composition, Humanities, and Social Science</b>	
English Composition or Communication .....	8
Electives to satisfy liberal education requirements .....	28
Technical or Professional Writing .....	4
<b>Other Courses</b>	
AgEn 1060—Agricultural Engineering Orientation .....	1
(to be taken by freshman students only)	
Computer Programming .....	3 or 4
(AgEn 1030, or CSci 1100 and 1101 or 3101)	
Electives as needed to meet graduation requirement of 190 cr	

Electives are usually chosen to develop professional competence in a given area of specialization, but they can be used for broad professional preparation. Sample programs and lists of suggested electives are available at the department office or from individual advisers.

## Architecture

(School of Architecture and Landscape Architecture)

Our environment exerts physical, emotional, and psychological influences on us and on our society. Unplanned and uncontrolled growth produces visual chaos, misuse of natural and other resources, and pollution; it has a detrimental effect on our quality of life.

Dramatic technological and scientific changes and the accelerated growth of population in urban areas have had a direct impact on the tasks of the architectural and environmental design professions. Many of the problems facing the world today fall within the areas of the architect's or designer's concern: inadequacy of housing, misuse of land and water resources, obsolescence of transportation systems, unplanned suburban sprawl, urban decay, and wasteful use of energy and materials. The urgency and critical nature of these problems demand a broader, more comprehensive approach to the education of architects, landscape architects, and environmental designers than in the past.

The spaces in which we live, move, work, and play are largely the product of our own devising. This process of devising and shaping the physical environment is the very essence of the art and science of architecture. Its greatest challenge is not the design of individual and isolated projects but the blending of many varied factors into a total cohesive and responsive physical environment, providing a full and rich life for all members of the community.

The design and planning process demands that the architect be trained in a wide variety of technical skills and possess a thorough understanding of social, political, and economic issues. In its educational philosophy the School of Architecture and Landscape Architecture is concerned with the design of the total environment and with the education of the total human being.

## Curricular Requirements

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The architecture program offers two 4-year preprofessional degrees and one 5-year professional B.Arch. degree.

**Bachelor of Environmental Design (B.E.D.) Curriculum** (4 years in Institute of Technology)—This program normally requires 1 year of pre-environmental design work followed by 3 years in the School of Architecture and Landscape Architecture. Students must complete a minimum of 192 credits of required and elective work.

This curriculum prepares students for continuation toward the B.Arch. degree, application for graduate study in architecture leading to the M.Arch. degree, or transfer into other disciplines such as urban design, city and regional planning, product design, or related fields.

**Bachelor of Arts (B.A.) Curriculum** (4 years in College of Liberal Arts)—This program normally requires 2 years of pre-architecture work followed by 2 years of work in the School of Architecture and Landscape Architecture. Students must complete 180 credits of required and elective work.

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

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

The B.A. program with a major in architecture is also offered through University extension.

**Bachelor of Architecture (B.Arch.) Curriculum** (5 years in Institute of Technology)—This program normally requires 1 year of pre-architecture work followed by 4 years in the School of Architecture and Landscape Architecture. Students must complete a minimum of 250 credits of required and elective work. The curriculum is intended for students who plan 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 required by laws of the various states.

Students will not be permitted to register in Arch 5122 until they have completed an approved graduation check sheet. Prior to registering for Arch 5123, students must present evidence that they have completed a minimum of 800 hours of practical experience; preferably, such experience should be in an architectural or planning office.

**Master of Architecture (M.Arch.) Program**—Programs in architectural design and urban design leading to the M.Arch. degree are open to students who meet the entrance requirements of both the Graduate School and the School of Architecture and Landscape Architecture. See the *Graduate School Bulletin* or the director of graduate studies in architecture for details.

## Special Programs

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

**Combined Degree Programs**—In architecture, landscape architecture, and planning.

*Computer Application*—(In collaboration with the University Computer Services) Students carry out projects involving application of computer programming and computer graphics to architecture, landscape architecture, and planning.

*Community Advocacy Design*—(In collaboration with the Urban Education Center) Students work with urban and rural communities on a variety of design projects.

*Built Environment Communication Center*—A program employing various forms of audiovisual media for educational and documentary use. It is anticipated this program will be the nucleus of graphic communication instruction and laboratory experience.

*Foreign Study Program*—Qualified students in the spring quarter of their third year of architecture or landscape architecture carry out their studies in various countries abroad.

*Project Ouroboros*—Studies of the architect's role in energy conservation through research. Students have designed and constructed two full-scale residences that demonstrate total energy conservation.

*Student Organization*—Students serve on architectural committees in the School of Architecture and Landscape Architecture, and have established a student coop.

## Admission Procedure

To enter the architecture program, students must submit an application on Form AR 110 by May 1 of the year of desired admission. Admission to the program is permitted only in the fall quarter unless advanced standing is granted. Students should apply to the University of Minnesota if not already a University of Minnesota student. Forms may be obtained from the Office of Admissions, 240 Williamson Hall, 231 Pillsbury Drive S.E., University of Minnesota, Minneapolis, Minnesota 55455.

To be considered for admission to the architecture program, a student must:

1. Have completed a minimum of 45 quarter credits (31 by the time of application).
2. Have fulfilled the following prerequisites with a minimum grade of C.  
2 quarters of English composition (Comp 1001-1002 or equivalent) . 8 credits  
2 quarters of calculus (Math 1211-1221 or equivalent)<sup>1</sup> . . . . .10 credits  
2 quarters of physics (Phys 1121-1122 or equivalent)<sup>1</sup> . . . . .10 credits  
3 quarters of environmental history (Arch 1001-1002-1003)<sup>2</sup> . . . . .12 credits
3. Submit an official transcript of all college work taken at the University of Minnesota and other colleges to date.
4. If desired, submit a portfolio of art or design work using an 8½- by 11-inch format. No other size will be considered. If the student desires to have the portfolio returned, a stamped, self-addressed envelope should be included.

It is recommended that applicants make an appointment with a counselor in the School of Architecture and Landscape Architecture before applying to discuss individual experience, professional development, motivation, or other pertinent information. Relevant data will be noted on the application.

<sup>1</sup>Students should note that the architecture curriculum requires 2 quarters each of calculus and physics. Since admission to the architecture program is limited, students may wish to substitute math and physics sequences that are acceptable for admission to other IT disciplines. Labs are required for all physics sequences.

<sup>2</sup>Students not enrolled on the Twin Cities campus must take this sequence for graduation, but it is not necessary for entry.

## Curricular Requirements

Students are selected on the basis of overall grade point average, college work completed, and art and design skills. Criteria for art and design skills are outlined on the application form. Preference for admission is given to Minnesota, Wisconsin, and North Dakota residents.

All students must begin Arch 3081 (Architectural Design I) in the fall quarter unless advanced standing is granted. Since the School of Architecture and Landscape Architecture can admit a limited amount of students, only those students who successfully meet the admission criteria will be allowed to register for Arch 3081. Additionally, promotion from one level of the design sequence to the next is by design faculty approval.

### Course Requirements

The pre-architecture and pre-environmental design programs, common for all students, are 1 year in length. They prepare students for the required course work in the School of Architecture and Landscape Architecture.

In both degree programs, each required course must be passed with a minimum grade of C. Courses in the pre-architecture and pre-environmental design programs are considered part of the respective curricula.

### PRE-ARCHITECTURE AND PRE-ENVIRONMENTAL DESIGN PROGRAMS

	Credits
Comp 1001-1002—Introductory Composition or Communication	8
Math 1211-1221—Analysis I, II	10
Phys 1121-1122—Physics for Architects	10
Arch 1021-1022-1023—History of Environmental Development	12
Arch 1010 or Liberal Education Elective	9
<b>Total Credits</b>	<b>49</b>

After substantial completion of the above work with a superior grade point average, students must apply for admission to the School of Architecture and Landscape Architecture on Form AR 110 before May 1 of the year of desired admission.

### B.E.D. PROGRAM<sup>1</sup>

Arch 1001-1002-1003—Environmental Design	12
ArtS 1107-1108-1109 <sup>2</sup> -3140—Drawing and Painting	12
Arch 3061-3062-3064-3065—Architectural Technology	20
AEM 3092-3093—Statics and Mechanics of Materials	8
Arch 3081 through 3093—Architectural Design	36
Approved Environmental Electives	18
Arch 3067—Integrated Design Systems	4
CE 3600-3601-3602—Structural Design	12
Arch 5051 through 5063—Architectural History (any three)	12
Liberal Education Electives	9
<b>Total Credits for Pre-Architecture Program</b>	<b>49</b>
<b>Total Credits</b>	<b>192</b>

### B.ARCH. PROGRAM<sup>1</sup>

Arch 3081 through Arch 5123—Architectural Design	84
ArtS 1107-1108-1109 <sup>2</sup> -3140—Drawing and Painting	12
AEM 3092-3093—Statics and Mechanics of Materials	8
Arch 3061-3062-3064-3065—Architecture Technology	20
CE 3600-3601-3602—Structural Design	12
Arch 5051 through Arch 5063—Architectural History (any three)	12
Arch 5115-5116—Structure and Form in Architecture	8
Arch 5126—Professional Practice	4
Arch 5137-5138—Planning	8
Liberal Education Electives	38
<b>Total Credits for Pre-Architecture Program</b>	<b>44</b>
<b>Total Credits</b>	<b>250</b>

<sup>1</sup>See the yearly handout, available in the architecture department office, for any changes in program requirements.

<sup>2</sup>Offered only after admission to School of Architecture and Landscape Architecture.

## Astronomy

(School of Physics and Astronomy)

An undergraduate program is offered leading to the B.S. degree in astrophysics. The English composition and foreign language requirements are identical to those for the physics program.

### GENERAL REQUIREMENTS

(Based on 180 credits)

	Credits
Liberal Education (see Physics listing) .....	36
Mathematics (see Physics listing) .....	33-37
<b>Astrophysics and Physics</b>	
Ast 3051-5161-5162—Astrophysics .....	12
Phys 1271-1281-1291—General Physics .....	12
Phys 1275-1285-1295—General Physics Laboratory .....	3
Phys 3011-3015—Oscillations, Oscillations and Waves Lab .....	5
Phys 3511-3512-3513—Modern Physics .....	12
Phys 5021-5022—Mechanics .....	8
Phys 5023-5024—Electricity and Magnetism .....	8
Ast 5990—Directed Research .....	3
Free electives to total 180 credits .....	44-48
Subtotal .....	180
English and/or foreign language as required .....	0-17
Total Credits .....	180-197

**Electives**—The curriculum above is a minimum program. The courses below provide a stronger program, particularly for those who intend to pursue graduate study.

#### *Recommended Physics and Astrophysics Courses*

Ast 1021-1025-1201—Introductory Astronomy  
 Ast 5163—Galactic and Extragalactic Astronomy  
 Phys 5101-5102—Quantum Mechanics  
 Phys 3201—Thermodynamics  
 Phys 5801—Modern Optics

#### *Suggested Technical Electives*

Statistics, Computer Programming  
 Geology  
 Chemistry  
 Meteorology  
 Cloud Physics  
 Cosmic Ray and Space Physics  
 History of Physics  
 Electronics

## Chemical Engineering

(Department of Chemical Engineering and Materials Science)

The chemical engineer is primarily a producer whose special province is to develop a process from its laboratory beginnings, through semiworks equipment, to full-scale production. Chemical engineering is based upon applications of chemistry, physics, mathematics, economics, and, occasionally, ecology as well as other aspects of biology. The chemical engineering curriculum includes study of applied mathematics; material and energy balances; properties and physics of gases, liquids, and solids; fluid mechanics; heat and mass transfer; thermodynamics; reaction kinetics; and process design, control, and optimization. Because of this broad-based foundation that emphasizes basic and engineering sciences, the chemical engineer is considered the universal engineer.

## Curricular Requirements

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Chemical engineers work on a wide variety of projects: basic and applied research, development work, design and modification of processes and equipment, and plant operation. Some enter sales, engineering, marketing, and management. Because of the breadth and flexibility of the chemical engineering curriculum, it is chosen by some students who plan to pursue graduate study in medical sciences, business administration, or patent law.

Chemical engineering deals with 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 operations are vital to the commercial success of industries based on chemical or physical transformation of matter. A chemist uses these operations qualitatively in a laboratory, but to apply them to a large-scale industrial process requires a chemical engineer who has a complete and quantitative understanding of the engineering as well as the scientific principles on which the operations rest.

Because many industries are based on some chemical or physical transformation of matter, the chemical engineer is much in demand. He or she may work in the manufacture of inorganic products—acids, alkalies, ammonia, paint pigments, fertilizers; in the manufacture of organic products—dyes, explosives, textiles, polymer fibers, rubber, rocket propellants, solvents, plastics, agricultural chemicals, pharmaceuticals, coal-based fuels, petroleum derivatives; 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 hydrocarbon fuels, nuclear materials, paper, glass, ceramics and cement concern the chemical engineer. Chemical engineers are particularly well suited for dealing with problems associated with disposal of industrial wastes and other forms of pollution that are of a chemical nature, as well as with environmental protection.

Chemical engineering underlies most of the energy field, including utilization of coal, petroleum, natural gas, tar sand, oil shale, geothermal deposits, solar radiation, and nuclear energy. The chemical engineer entering the nuclear industry may deal with materials for nuclear reactors and with design and operation of reactors for research, isotope production, heat and power production, and utilization as well as storage of radionuclides and fission products.

The chemical engineer may also enter the field of bioengineering, where problems range from utilization of the activities of microorganisms, to manufacture of foods, to design of prosthetic devices and artificial human organs.

**Degree Requirements**—To receive the bachelor of chemical engineering degree, students must normally complete required and elective course work totaling 200 credits (although the minimum, in special cases, may be 191 credits). Students must satisfy the IT minimum liberal education requirements (a total of 36 credits including at least 7 in biological science) as part of a pre-chemical engineering program (96-105 credits) and complete a coherent degree program of science and technical courses (86-104 credits). Both predegree and degree curricula are outlined below.

The student, together with her or his adviser, plans the degree program in two stages: a 1-year plan is submitted at the start of the third year, and, ordinarily, a complete 4-year program is submitted for certification by the department by the beginning of the fourth year. By selecting appropriate technical electives and, in certain cases, substituting courses with approval of the adviser and department, students can emphasize various special interest areas in their upper division curriculum. Sample programs that illustrate these possibilities are available from the depart-

mental office, 151 Chemical Engineering. Advisers and the department's director of undergraduate studies can be contacted through the same office.

**Cooperative Programs**—Coop programs may be arranged by a student with an appropriate employer when the job offers professional training in the field of study. Such arrangements can receive departmental approval and cooperation.

Two work-study schedules are recommended: 1) work summers (June 16 through September 15) through third year, continue working during fall and winter quarters of fourth year, return to University for spring quarter, work summer, return to University for fall and winter quarters of fifth year, and have option to graduate at the end of winter quarter of that year; or 2) work summers through third year, continue working through following academic year and following summer, return to University for fifth year, and graduate at end of the spring quarter of that year.

To facilitate schedule one, the department will allow substitutions for required courses in the spring quarter of the fifth year that have as prerequisites courses to be completed in the previous fall and winter quarters.

To preserve educational continuity and student status, coop students working during the regular academic year, may register during work quarters for 1 credit of Special Projects (ChEn or MatS 5902f, 5903w, 5904s). Written reports to the adviser will be required to earn these credits. Two credits of Special Projects courses may be used to satisfy one of the 2-credit laboratory courses required for the bachelor's degree.

**Transfer Students**—Students intending to transfer from another campus or school should take equivalent courses available to them. Students with questions about a proposed transfer are encouraged to write or visit the Department of Chemical Engineering and Materials Science, 151 Chemical Engineering, 421 Washington Avenue S.E., University of Minnesota, Minneapolis, Minnesota 55455.

## LOWER DIVISION

### First Year

	Credits		
	f	w	s
Comp 1001-1002—Introductory Composition .....	4	4	...
Math 1311-1321-1331—Computer Calculus I, II, III (or) Math 1211-1221-1231—Analysis I, II, III .....	5	5	5
Chem 1031, 1032—General Principles I, II .....	5	5	...
Phys 1271, 1275—Mechanics, General Physics Laboratory .....	...	...	5
Liberal Education Electives (quarters of registration may be rearranged with Comp 1001, 1002) .....	...	0-4	4-8

### Second Year

Chem 3331, 3332, 3335, 5126—Introductory Organic Chemistry I, II with Laboratory (II), Modern Analytical Chemistry .....	5	5	4
Chem 5533, 5536—Quantum Mechanics with Laboratory .....	...	...	6
Phys 1281-1291—Heat and Electricity, Magnetism and Optics .....	4	4	...
Phys 1285-1295—General Physics Laboratory .....	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 Engineers and Physical Scientists (or approved biology alternative) .....	...	4	...
GCB 3201—Molecular Biology (or approved biology alternative) .....	...	...	3-4
Liberal Education Elective (quarters of registration may be rearranged with EBB 3101) .....	0-4	...	...

## Curricular Requirements

Note that the lower division curriculum in chemical engineering is the same as the lower division curriculum in chemistry, except that courses in biology and ecology are included. The lower division curriculum in chemical engineering differs from those in other engineering fields because chemical engineering requires more chemistry course work.

Also note that the lower division courses EBB 3101 and GCB 3201 (or approved substitutes) fill both chemical engineering and liberal education requirements.

### 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 .....	3	...	...
ChEn 5401—Chemical Engineering Laboratory .....	...	...	2
Chem 5534—Chemical 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	...	...
Chem 5535, 5538—Statistical Mechanics and Reaction Kinetics with Laboratory .....	...	...	5
Liberal Education Electives .....	0-4	3-5	4-8

#### Fourth Year

ChEn 5104—Separation Processes .....	4	...	...
ChEn 5501, 5502—Process Evaluation and Design .....	...	4	4
ChEn 5301—Chemical Reactor Analysis .....	4	...	...
ChEn 5601, 5604—Process Control, Laboratory <sup>1</sup> .....	...	4	2
ChEn 5402, 5403—Chemical Engineering Laboratory <sup>1</sup> .....	2	2	...
ChEn 5901—Chemical Process Laboratory <sup>1</sup> .....	2	...	...
Technical Electives .....	3-4	3-4	6-8
Liberal Education Electives .....	3-4	3-4	6-8

Students interested in bioengineering should contact Professor Tsuchiya in fall quarter of their 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.

## Chemistry

The chemistry curriculum includes courses in chemistry, physics, mathematics, English, and German that cover the background necessary for a successful career in this field. After the required courses have been completed there are no restrictions on the remaining courses the student chooses.

Specific requirements are:

1. A minimum of 180 credits for graduation. All required courses including German but excluding freshman English must be taken A-N.
2. Freshman English (8 credits) or exemption.
3. One year of German (15 credits) to acquire ability to read the literature of the field in German.

<sup>1</sup>Programs normally include at least three laboratory courses.

4. One year of calculus-based physics (15 credits).
5. Five quarters (25 credits) of mathematics.
6. Sixty credits of chemistry.
7. Minimum liberal education requirements (36 credits). Eight credits of English, if taken, and 8 credits of German may be included in this total.
8. Electives (35-40 credits), chosen by the student in consultation with his or her adviser, but otherwise without restriction.

The department will consider substitutions for any item in the required curriculum upon petition to the director of undergraduate studies. Permission for any substitutions contemplated must be requested before the quarter the required course would normally be taken.

**Electives**—The detailed list of courses for the chemistry, mathematics, and physics requirements is presented in the recommended schedule below. The English and German courses are included in the electives in the schedule.

In addition to advanced courses in the conventional fields of chemistry—analytical, inorganic, organic, and physical—students are encouraged to take the following chemistry courses:

3499—Senior Thesis  
 5522, 5523, 5524—Physical Biochemistry  
 5601—Bioorganic Chemistry  
 5610—Principles of Polymer Science  
 3970—Directed Study  
 5580—Physical Chemistry of Polymers  
 5801, 5802, 5803—Industrial Chemistry

Other areas recommended for consideration for elective work are:

Astronomy	Mathematics
Biochemistry	Medicinal Chemistry
Biology	Microbiology
Botany	Physics
Chemical Engineering	Physiological Chemistry
Computer Science	Physiology
Ecology	Plant Physiology
Economics	Zoology
Food Science and Nutrition	

## LOWER DIVISION

### First Year

	Credits		
	f	w	s
Chem 1031, 1032, 1133—Chemical Principles I, II, Elementary Quantitative Analysis .....	5	5	5
Math 1311-1321-1331—Computer Calculus I, II, III (or) Math 1211-1221-1231—Analysis I, II, III .....	5	5	5
Electives (quarters of registration may be rearranged with Comp 1001-1002) .....	4-8	4-8	4-8

### Second Year

Chem 3331, 3332, 3333—Introductory Organic Chemistry I, II, III .....	5	3	3
Chem 3335, 3336—Introductory Organic Chemistry Laboratory II, III .....	...	2	2
Math 3211, 3221—Analysis IV, Linear Algebra and Differential Equations .....	5	5	...
Phys 1271-1281-1291—General Physics .....	4	4	4
Phys 1275-1285-1295—General Physics Laboratory .....	1	1	1
Electives .....	0-3	0-3	4-8

## Curricular Requirements

### UPPER DIVISION

#### Third Year

	Credits		
	f	w	s
Chem 5534—Chemical Thermodynamics .....	4	...	...
Chem 5535, 5538—Statistical Mechanics and Reaction Kinetics (plus lab) .....	...	4, 1	...
Chem 5533, 5536—Quantum Chemistry (plus lab) .....	...	...	4, 2 <sup>1</sup>
Chem 5133—Chemical Instrumentation and Analysis .....	...	...	5
Electives .....	9-13	9-13	4-8

#### Fourth Year

Chem 5731, 5732—Inorganic Chemistry I, II .....	3 <sup>1</sup>	3 <sup>1</sup>	...
Chem 5734, 5735—Inorganic Chemistry Laboratory I, II .....	2 <sup>1</sup>	2 <sup>1</sup>	...
Electives .....	9-13	9-13	14-18

## Civil Engineering

(Department of Civil and Mineral Engineering)

Civil engineering deals with the science and art of engineering, applied to solving problems related to the human environment and natural resource needs.

Students interested in developing and applying scientific and technological innovations, as well as in providing service to others, will find a strong appeal in civil engineering. This field requires high professional competence coupled with an understanding of social goals and government structures in order to meet the challenge of adapting the environment for the health and benefit of human beings.

There are professional opportunities for civil engineers in both private practice and public service. Graduates may pursue careers in design, construction, maintenance, management, or research and development. Many find employment in federal, state, and municipal agencies. Whether the setting is a complex urban area or a developing population and industrial center, civil engineers serve the public as planners, designers, and supervisors of transportation systems, pollution control facilities, water resources projects, private and public utility enterprises, and other civil works.

The bachelor of civil engineering (B.C.E.) degree program requires a minimum of 194 credits. The first 2 years are similar to lower division curricula in other IT engineering departments. Students may transfer to civil engineering from another IT engineering department or from a community college. Students who transfer to the program after completing the first 2 years at another institution must complete a course in statics (AEM 1015), which is a prerequisite for many third-year CE courses, prior to entering the University if they expect to complete the program in 2 additional years. The last 2 years of the civil engineering program emphasize engineering science and engineering practice.

Principal fields within civil engineering are:

**Structural Engineering**—The design and analysis of buildings, bridges, industrial facilities, and other structures built with concrete, steel, reinforced or prestressed concrete, wood, and other materials.

**Geotechnical Engineering**—The analysis of the properties of soils and rocks and applications to the design of foundations, retaining walls, roads, slopes, dams, and tunnels.

<sup>1</sup>A student who wishes to complete the required chemistry courses in the first 3 years may take Quantum Chemistry (5533 and 5536) in the third quarter of the second year and Inorganic Chemistry (5731, 5732, 5734, and 5735) in the first 2 quarters of the third year.

*Water Resources Engineering*—The application of fluid mechanics and hydrology as well as other basic knowledge to the design and operation of water resources systems, including hydrologic analysis; hydraulic design of channels, pipelines, pumping stations, dams and reservoirs; hydrothermal power development; environmental transport processes; sedimentation; coastal engineering and harbor development; irrigation and drainage; and wastewater disposal. The St. Anthony Falls Hydraulic Laboratory, a part of the Department of Civil and Mineral Engineering, is the site of water resources research.

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

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

*Surveying and Mapping*—The art and science of locating points and objects on, above, and under the surface of the earth for planning, design, and construction. This field includes geodesy, photogrammetry, and land surveying.

Interdisciplinary programs in areas of current national interest, particularly in environmental engineering, water resources engineering, and transportation, are offered through the cooperation of civil engineering and other IT departments.

A limited number of civil engineering students may enter an engineering intern program after completing approximately 5 quarters of study. Participants alternate study quarters with two 6-month work periods, for which they earn 4 credits each period.

General requirements for the bachelor of civil engineering degree are listed below, followed by a sample curriculum illustrating how these requirements and appropriate electives can be combined. Other sample programs are available from the Director of Undergraduate Studies, Department of Civil and Mineral Engineering Student Office, 103 Experimental Engineering, 208 Union Street S.E., University of Minnesota, Minneapolis, Minnesota 55455.

By selecting appropriate elective courses, students may develop a minor field of study or may specialize in an area of interest.

## GENERAL REQUIREMENTS

	Credits
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, General Physics Laboratory	15
Chem 1004-1005, or 1031, 1032—General Chemistry	10
Geo 1001 or 1001H or 1111—Physical Geology	5
CE 1001—Civil Engineering Orientation	1
CSci 3101; or 1100, 1101—FORTRAN Programming	4
Stat 3091—Probability, Statistics	4
CE 3500—Introduction to Environmental Engineering Problems and Analysis	4
AEM 1015—Statics	4
AEM 3016—Deformable Body Mechanics	4
CE 3100—Introduction to Surveying and Mapping	4
CE 3200—Introduction to Transportation Engineering	4
CE 3300—Soil Mechanics	4
CE 3400—Fluid Mechanics	4
CE 3700—Introduction to Construction Materials	4
CE 5002—Engineering Economics	2
CE 5401—Water Resources Engineering	4
CE 5405—Hydrology and Hydrologic Design	4
CE 5505—Water Quality and Treatment	4
CE 5600—Linear Structures	4

# Curricular Requirements

	Credits
CE 5611—Design of Reinforced Concrete Structures (or) CE 5610—Design of Metal Structures	4
Technical Elective—one course chosen from EE 3000—Circuits, EE 3002—Electric Machinery and Power Distribution, or ME 3301—Thermodynamics	4 or 5
Liberal Education Electives <sup>1</sup>	36
Free Electives <sup>2</sup>	7 or 8
Total Credits	166

## SENIOR ELECTIVE PROGRAM

(28 credits)

The senior elective program provides additional education in one or more areas. Students who maintain a GPA of 3.30 or higher are permitted to choose up to 8 credits of 8000-level courses as part of their senior elective program.

Courses for the program are listed below. Four areas of emphasis are available: structures and geotechnical engineering, water resources and environmental engineering, transportation, and surveying. Courses in each area of emphasis are divided into two categories: design oriented (A) and engineering oriented (B). Four courses are required from category A, of which at least three must be in one area of emphasis. Three courses are required from category B. One of the courses CE 5097, 5098, or 5099, Advanced Design, Analysis Research, or Tutorial in Civil Engineering, may be substituted for a course in category A.

<b>1. Structures and Geotechnical Engineering</b>	Credits
A. CE 5001—Contracts and Specifications	4
CE 5610—Design of Metal Structures <sup>3</sup>	4
(or) CE 5611—Design of Reinforced Concrete Structures <sup>3</sup>	4
CE 5612—Intermediate Design of Metal Structures	4
CE 5613—Intermediate Reinforced Concrete Design	4
CE 5311—Shear Strength of Soils	4
CE 5310—Design of Foundations	4
CE 5312—Design of Slopes and Embankments	4
CE 5321—Slopes and Foundations I	4
CE 5322—Slopes and Foundations II	4
CE 5601—Analysis of Structures	4
CE 5701—Cemented Materials	4
CE 5702—Manufacture and Quality Control of Construction Materials	4
B. AEM 3036—Dynamics	4
AEM 5580—Introduction to Solid Mechanics	4
AEM 5581—Mechanics of Elastic Solids	4
CE 5320—Fundamentals of Geomechanics	4
CSci 5301—Numerical Analysis	4
EE 3002—Electric Machinery and Power Distribution	4
Geo 5002—Structural Geology	4
Geo 5251—Geomorphology	4
GeoE 5347—Computer Applications in Geo-Engineering	4
Math 3231—Vector Analysis	4
Math 5512—Differential Equations	4
Math 5567—Fourier Series and Boundary Value Problems	4
ME 3301—Thermodynamics	4
<b>2. Water Resources and Environmental Engineering</b>	
A. CE 5001—Contracts and Specifications	4
CE 5402—Hydraulic Analysis With Computer Applications	4

<sup>1</sup>One course should be in economics.

<sup>2</sup>Technical electives are recommended. Physical education credits are not acceptable. Credits received for the engineering intern program will be included in these electives. Students who have not taken graphics in high school should complete EG 1025—Engineering Graphics.

<sup>3</sup>Only students who successfully complete both CE 5610 and 5611 will be qualified to take the Minnesota registration examination for structural engineers.

	Credits
CE 5410—Open Channel Hydraulics	4
CE 5420—Introduction to Water Resources Management	4
CE 5500—Analysis and Design of Water Supply Systems	4
CE 5501—Analysis and Design of Wastewater Systems	4
CE 5510—Solid Waste Management	4
<b>B. Biol 3013—Microbiology</b>	<b>4</b>
CE 5320—Fundamentals of Geomechanics	4
CE 5435—Intermediate Fluid Mechanics	4
Chem 3301, 3302—Elementary Organic Chemistry	8
Chem 5520, 5521—Elementary Physical Chemistry	6
CSci 5301—Numerical Analysis	4
EE 3000—Circuits	4
ME 3301—Thermodynamics	4
Geo 3101—Surficial Geologic Processes	5
Geo 5601—Limnology	4
Geo 5611—Groundwater Geology	4
GeoE 5437—Computer Applications in Geo-Engineering	4
<b>3. Transportation</b>	
<b>A. CE 5001—Contracts and Specifications</b>	<b>4</b>
CE 5200—Geometric Design of Highways	4
CE 5201—Highway Traffic Characteristics	4
CE 5202—Airport Design	4
CE 5210—Introduction to Transportation Planning	4
CE 5304—Highway and Airport Pavements	4
CE 5701—Cemented Materials	4
CE 5702—Manufacture and Quality Control of Construction Materials	4
<b>B. CSci 5301—Numerical Analysis</b>	<b>4</b>
Geog 5372—Metropolitan Analysis I	4
Geog 5373—Metropolitan Analysis II	4
Geog 5383—Transportation Geography	4
IEOR 5000—Introduction to Industrial Engineering Analysis	4
IEOR 5710—Transit System Analysis and Design	4
IEOR 5711—Transit System Analysis and Design	4
Stat 5021—Statistical Analysis I	4
Stat 5022—Statistical Analysis II	4
<b>4. Surveying<sup>1</sup></b>	
<b>A. CE 3103—Field Surveying</b>	<b>3</b>
CE 5001—Contracts and Specifications	4
CE 5100—Land Surveying	4
CE 5102—Site and Route Engineering	4
CE 5103—Land Planning and Subdivision Design	4
<b>B. CE 5101—Geodesy</b>	<b>4</b>
CE 5104—Photogrammetry	4
CE 5105—Survey Adjustments	4
CSci 5301—Numerical Analysis	4
FR 5352—Remote Sensing	4
GeoE 5437—Computer Applications in Geo-Engineering	4

**SAMPLE PROGRAM**

**First Year**

f	Credits	w	Credits	s	Credits
Math 1211	5	Math 1221	5	Math 1231	5
Comp 1001	4	Comp 1002	4	Phys 1271, 1275	5
Chem 1004	5	Chem 1005	5	Geo 1001	5
CE 1001	1	CSci 1100	2	CSci 1101	2
	15		16		17

<sup>1</sup>By completing appropriate courses, a student may be permitted to take the Land Surveyor in Training examination upon graduation.

## Curricular Requirements

### Second Year

f	Credits	w	Credits	s	Credits
Math 3221	5	Math 3211	5	Stat 3091	4
Phys 1281, 1285	5	Phys 1291, 1295	5	CE 3100	4
AEM 1015	4	AEM 3016	4	Econ 1001	4
CE 3500	4	EG 1025	4	CE 3400	4
	18		18		16

### Third Year

CE 3700	4	CE 5505	4	CE 3200	4
CE 3300	4	CE 5600	4	CE 5610	4
CE 5401	4	CE 5405	4	CE 5002	2
EE 3002	5	CLE	4	CLE	4
	17		16		14

### Fourth Year

CE(A)	4	CE(A)	4	CE(A)	4
CE(A)	4	CE(B)	4	CE(B)	4
CE(B)	4	CLE	4	Elective	3
CLE	4	CLE	4	CLE	4
	16		16		15

## Master's Degree Programs

Because of the rapid development in technology, many students prepare themselves for advanced professional work by completing graduate study. Those who have a maximum of 9 credits to complete for their baccalaureate degree, and who have a satisfactory academic record, may be admitted to study for a master's degree program; and 9 credits earned during the last term of undergraduate study may be applied to the master's program. Two master's degree programs, the M.S. and M.C.E., are available. Each requires about 1 year to complete. Information about these programs will be provided by the director of graduate studies of the department.

## Computer Science

Computer science is concerned with the study of the hardware and software (programming) aspects of high speed computing devices and with the application of these devices to the solution of a broad spectrum of technological and business problems. A bachelor's degree in computer science can be earned in either the College of Liberal Arts or the Institute of Technology. Details of the former program can be found in the *CLA Bulletin*. Both programs are designed to give a student a broad foundation in the basic subjects of computer science. By means of an upper division option and a choice of alternatives in the required courses, the curriculum allows a student to develop a concentration within computer science or in interdisciplinary areas involving the applications of computers. This should prepare a student for a variety of industrial and governmental positions involving computer usage or for graduate work in the field.

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

In addition to the required courses, a student must satisfy the liberal education requirements for the Institute of Technology and complete approved electives. A minimum of 187 or 188 credits are required for graduation.

All IT courses in the required program as well as the 32 credits that 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**—After the sophomore year, students who have completed elementary physics and a higher level programming language may enter the program as juniors, assuming that their liberal education courses are roughly equivalent to those required by the Institute of Technology. Most transfer students have not studied the material covered in CSci 3104, 3105, 3106, and 3107; however, a program can be worked out in which these courses are taken during the summer and the junior year. All transfer students should visit the departmental office for information.

**LOWER DIVISION**

	Credits
Freshman English or Communication .....	8
Math 1211, 1221, 1231 (or) Math 1311, 1321, 1331—Analysis .....	15
Math 3142, 3211 (or) Math 3511, 3211 (for students with better than average mathematical ability) (or) Math 3511, 3521 (for students with high mathematical ability) .....	9 or 10
Stat 3091—Probability, Statistics (or) Stat 5121—Theory of Statistics <sup>1</sup> .....	4
Phys 1271, 1281, 1291—General Physics .....	12
Phys 1275, 1285, 1295—General Physics Laboratory .....	3
CSci 3001—Perspectives on Computers and Society .....	4
CSci 3104—Introduction to Programming and Problem Solving .....	4
CSci 3105, 3106—Fundamentals of Algorithms and Languages I, II .....	8
CSci 3107—Introduction to the Structures and Programming of Computer Systems .....	4
Liberal Education Electives .....	20
Total Credit Minimum .....	91 or 92

**UPPER DIVISION**

Engl 3085—Technical Writing .....	4
Liberal Education Electives .....	8
Electives .....	24
<b>Required Technical Courses:</b>	
CSci 3400—Discrete Structures .....	4
CSci 5102—Structure and Programming of Software Systems II .....	4
CSci 5106—Higher Level Languages .....	4
CSci 5121—Data Structures .....	4
CSci 5201—Introduction to Computer Architecture .....	4
CSci 5301—Numerical Analysis .....	4
CSci 5400—Introduction to Automata Theory .....	4
<b>Upper Division Option</b>	
Elective courses that form a coherent program in computer science and applied areas; e.g., health sciences, transportation, biomedical engineering, environmental engineering, machine design, software systems, mathematics of computation, theory of computation. These courses are to be selected from additional 5000-level CSci courses and adviser-approved courses from other departments. See option program information available in departmental office .....	
Total Credit Minimum .....	96

**Electrical Engineering**

The electrical engineering program seeks to prepare its graduates to deal with beginning engineering assignments and to provide a foundation for continued professional development. This dual objective is reflected in the continual updating that the program undergoes to keep up with the rapid changes in the field.

The electrical engineering curriculum offers students an opportunity concentrate in a number of specialized areas or in related interdisciplinary studies. These areas include control or communications engineering, bioengineering, computer systems, energy conversion and power systems, and electronic devices and circuit design.

<sup>1</sup>Students intending to complete additional work in statistics must take Stat 5121 rather than Stat 3091.

## Curricular Requirements

An honors program and an engineering intern program are available to qualified upper division students. The honors program offers an opportunity for greater depth of study through special recitation sections, an individual honors project completed under faculty guidance, and increased elective choice. The engineering intern program features industrial experience and some financial support through alternate quarters of on-campus study and off-campus industrial assignment during a 2-year period.

The degree of bachelor of electrical engineering (B.E.E.) degree, granted after completion of the 4-year curriculum, requires a minimum of 190 quarter credits. Curricular details, sample elective programs, and quarterly schedules for the B.E.E. program can be obtained by writing to the Department of Electrical Engineering, 139 Electrical Engineering, 123 Church Street S.E., University of Minnesota, Minneapolis, Minnesota 55455.

### LOWER DIVISION

	Credits
Liberal Education Electives, including 8 cr	
Freshman Composition or Communication	18
Math 1211-1221-1231, 3211, 3221, 3231—Analysis I-IV, Introduction to Linear Algebra and Differential Equations, Vector Analysis	29
Natural Sciences	
Phys 1271-1281-1291—General Physics	12
Phys 1275-1285-1295—General Physics Laboratory	3
Chem 1004-1005—General Principles of Chemistry (or) Chem 1014—General Principles of Chemistry, and modern physics or other appropriate science elective	8-10
EE 1000—Introduction to Electrical Engineering	1
CSci 1100-1101—FORTRAN Programming	4
EE 1510—Elements of Electrical Engineering	5
Technical Elective (AEM 3036 or Stat 3091 or ME 3301)	4
Free Electives	8-10
<b>Total Credits</b>	<b>94</b>

### UPPER DIVISION

EE 3010-3011-3012—Circuits, Signals, and Systems I-II-III	12
EE 3050-3051—Electronics I-II	8
EE 3100-3101—Electromagnetic Fields I-II	8
EE 3400-3401-3402—Junior EE Laboratory	8
EE 5050—Nonlinear Electronic Circuits	4
EE 5100—Electromagnetic Fields III	4
EE 5101—Electromagnetic Fields Laboratory	1
Comp 3085—Technical Writing	3
Senior Technical Program	28
Free Electives (including liberal education courses to satisfy the CLE requirements)	20
<b>Total Credits</b>	<b>96</b>

## Geo-Engineering

(Department of Civil and Mineral Engineering)

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

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. Concerns may include dam site studies and selection, foundations, slope stabili-

ty and design, erosion control, drainage, irrigation, highway subgrades, and tunneling and underground excavation.

The mineral industries, including metal and coal mining, petroleum, and industrial raw materials. Activities may include analysis and design in the exploration and development of minerals, mineral valuations, and application of geochemical, geophysical, and geological 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 other areas.

Government bureaus and other agencies, involving environmental studies, geothermal energy, water resources, underground transit systems, and similar concerns.

Depending on his or her interests, the geological engineer may work for mining or petroleum companies, consulting engineering groups, construction companies, research organizations, or government agencies. A high degree of specialization within the broader professional field usually requires some postgraduate study.

The undergraduate curriculum provides training in engineering geology and related topics such as geomechanics, and has sufficient flexibility to allow the student to obtain a limited degree of specialization in one of the fields with which geo-engineers are concerned. It also offers a good foundation for graduate study.

The 4-year program leads to the degree of bachelor of geo-engineering (B.Geo.E.). A minimum of 192 credits are required for graduation. The program includes field trips.

The following program includes the required courses and a recommended schedule. It can be modified, in consultation with the faculty adviser, to meet individual student interests. The final program must be approved by the adviser for graduation.

**LOWER DIVISION—ALL OPTIONS**

**First Year**

	Credits		
	f	w	s
Math 1211-1221-1231—Analysis I, II, III .....	5	5	5
Chem 1004-1005—General Chemistry .....	5	5	...
Comp 1001-1002—Introductory Composition .....	4	4	...
Phys 1271—General Physics .....	...	...	4
Phys 1275—General Physics Laboratory .....	...	...	1
Liberal Education Electives .....	...	...	4

**Second Year**

Math 3221—Introduction to Linear Algebra, Linear Differential Equations .....	5	...	...
Phys 1281-1291—General Physics .....	4	4	...
Phys 1285-1295—General Physics Laboratory .....	1	1	...
AEM 1015—Statics .....	...	4	...
AEM 3016—Deformable Body Mechanics .....	...	...	4
Stat 3091 or ME 3900—Statistics .....	...	...	4
CSci 1100—Introduction to FORTRAN Programming .....	...	2	...
CE 3400—Fluid Mechanics .....	...	...	4
EG 1025—Engineering Graphics .....	4	...	...
Liberal Education Electives .....	4	4	4

**UPPER DIVISION—GEOMECHANICS INTEREST**

**Third Year**

MinE 5611, 5612, 5613—Mineral Resources I, II, III .....	4	4	4
GeoE 5216—Geo-Engineering .....	...	3	...
GeoE 5320—Fundamentals of Geomechanics .....	4	...	...
GeoE 5321—Slopes and Foundations I .....	...	4	...

## Curricular Requirements

	Credits		
	f	w	s
GeoE 5322—Slopes and Foundations II .....	...	...	4
Geo 1111, 3401—Physical Geology, Introductory Mineralogy .....	5	5	...
Geo 3103—Structural and Field Geology .....	...	...	5
CE 3300—Elements of Soil Mechanics .....	4	...	...
CE 3100—Surveying .....	...	...	4
Liberal Education Electives .....	4	...	...
Geology Summer Field Trip (4 weeks or more) .....	...	...	6

### Fourth Year

GeoE 5262—Geo-Engineering Analysis .....	...	...	4
GeoE 3012—Geo-Engineering Surveying .....	...	...	2
GeoE 5437—Computer Applications in Geo- and Mineral Engineering .....	4	...	...
Geo 5611—Groundwater Geology .....	...	...	4
Geo 5512—Principles of Seismic Exploration .....	...	3	...
Geo 5513—Principles of Electrical Exploration .....	...	...	3
CE 5600—Linear Structural Systems .....	...	4	...
Technical Electives .....	4	5	4
Liberal Education Electives .....	8	4	...

## UPPER DIVISION—EXPLORATION INTEREST

### Third Year

MinE 5611, 5612, 5613—Mineral Resources I, II, III .....	4	4	4
MinE 5800—Mineral Processing .....	4	...	...
GeoE 5216—Geo-Engineering .....	...	3	...
Geo 1111, 3401—Physical Geology, Introductory Mineralogy .....	5	5	...
Geo 3103—Structural and Field Geology .....	...	...	5
CE 3100—Surveying .....	...	...	4
Liberal Education Electives .....	4	4	4
Geology Summer Field Trip (4 weeks or more) .....	...	...	6

### Fourth Year

GeoE 5180—Geochemical Exploration .....	3	...	...
GeoE 5437—Computer Application in Geo- and Mineral Engineering .....	4	...	...
GeoE 5262—Geo-Engineering Analysis .....	...	...	4
GeoE 3012—Geo-Engineering Surveying .....	...	...	4
MinE 5642—Mineral Economics .....	...	3	...
MinE 5830—Microscopy for Mineral Engineers .....	...	...	3
Geo 5351—Metal Sulphide Deposits .....	4	...	...
Geo 5512—Principles of Seismic Exploration .....	...	3	...
Geo 5513—Principles of Electrical Exploration .....	...	...	3
CE 3300—Elements of Soil Mechanics .....	4	...	...
Technical Electives (geology or geo-engineering) .....	...	4	...
Technical Electives .....	...	8	...
Geology Electives .....	...	...	4

## Geology and Geophysics

The Department of Geology and Geophysics offers two undergraduate programs, one in geology and one in geophysics. A minimum of 189 credits are required for completion of the B.S.Geol. or B.S.Geophys. degree program.

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, ocean-

ography, and various branches of civil engineering. Potential employers are private industry, research institutions, universities, and 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, and chemistry. The geophysics program emphasizes the first two. The geology program is built around a core of seven basic courses taken during the second and third years. Some students select a geology or geophysics major simply to obtain this broad science base.

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; and magnetic, thermal, and electrical properties applied to topics ranging from continental drift to mineral exploration.

Selection of a degree program should be made during the second year, although a later decision is possible. Both degree programs offer a good foundation for students preparing for graduate work or for those planning to terminate with a bachelor's degree.

**GENERAL REQUIREMENTS**

	Credits
CLE requirements .....	36
Specific courses required of all students. These should be taken on A-N grading except Engl 3085.	
Core Geology Courses—Should be taken in order shown, if possible .....	39
Sophomore Year: fall Geo 1111—Introductory Physical Geology (5 cr) winter Geo 3401—Mineralogy (5 cr) spring Geo 3102—Petrology (5 cr)	
Junior Year: fall Geo 3101—Surticial Processes (5 cr) winter Geo 3112—Earth History (5) spring Geo 3103—Structural Geology (5 cr)	
Summer After Junior Year: Geo 5110—Field Camp (9 cr)	
Math 1211, 1221, 1231, 3211 (should be taken as early as possible, preferably beginning in the freshman year) .....	20
Phys 1271, 1275, 1281, 1285, 1291, 1295 (should be taken early if possible) .....	15
Chem 1004, 1005 (should be taken early, preferably in the freshman year; Chem 1004 is a prerequisite for Geo 3401—Mineralogy) .....	10
Engl 3085—Technical Writing (should be taken late in junior or early in senior year) .....	4
Free Electives .....	20
Subtotal .....	144

**ADDITIONAL REQUIREMENTS FOR IT GEOLOGY MAJORS**

These courses should be taken on A-N grading, unless available only on S-N. Specific courses should be chosen in consultation with the adviser.

Additional cognate sciences to total at least 29 credits, including:

Math 3221 (recommended for most students) or Stat 3091 .....	4 or 5
Chem 1006, 5520, and Chem 5521 or Geo 5301 (or) Chem 3301, 3302 (or) BioC 1301, 1302 .....	9 or 10

Additional science credits chosen from:

- Physics (3000 level or above; 3501 recommended)
- Mathematics (3000 level or above; 3231 recommended)
- Chemistry (3000 level or above)
- Biology (Biol 1011 is prerequisite for other biology courses; no more than one additional 1000-level course from the College of Biological Sciences can be applied)

## Curricular Requirements

	Credits
CE 3400	
GeoE 5216	
Computer Science (no more than 4 cr at 1000 level can be applied)	
Other science courses, as suitable, with departmental consent	14-16
Minimum Additional Requirements	29
Additional geology or geophysics electives, to be chosen from 5000 level or above. Geo 3099 may be used, but 8008 may not	16
Subtotal	45
Total Credits Required for Geology Major	189

### ADDITIONAL REQUIREMENTS FOR IT GEOPHYSICS MAJORS

Phys 3501, 3505, 3011	9
Math 3221	5
Geophysics chosen from Geo 5500 series courses	9-12
Geology, mathematics, physics, electrical engineering, chemistry, or computer science courses chosen in consultation with the adviser from the following	19-22
Geo 3099, 5351, 5611	
Math 3231, 3142, 5512, 5457-5458-5459, 5601-5602-5603	
Stat 3091 or 5131	
Phys 5011-5012-5013 or 5021-5022, 5023-5024, 5851	
EE 3100-3101 may be substituted for Phys 5023-5024; 3000-3001 may be substituted for Phys 5851	
Chem 5520, and 5521 or Geo 5301	
CSci 1100-1101 or 3101	
Subtotal	45
Total Credits Required for Geophysics Major	189

## Industrial Engineering/Operations Research

(Department of Mechanical Engineering)

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

Industrial engineering is concerned with the design, improvement, and installation of integrated systems of labor, 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—Advanced Mechanical Engineering Laboratory	
ME 5260—Engineering Materials and Processing	
ME 5254—Design Morphology With Applications	
Liberal Education Electives	18
Coherent Elective Program <sup>1</sup>	22

## Graduate Study in Industrial Engineering and Operations Research

Graduate programs in operations research and industrial engineering, leading to the M.S. and Ph.D. degrees, are available to students who meet the entrance requirements of the Graduate School. See the *Graduate School Bulletin* for specifics.

## Landscape Architecture

(School of Architecture and Landscape Architecture)

Landscape architecture is concerned with the impact, disposition, and management of natural resources as well as the quality of experience that results from the development of land for specific human use.

The landscape architect is concerned with a wide range of projects: large-scale regional landscape planning; design of exterior environments for working, living, and recreation; commercial, institutional, and industrial development; transportation systems; and multiple-use areas. This range may vary in scale from single family residences to regional open space systems. Professional services include land use feasibility studies, site selection studies, site layout proposals, detail grading, construction drawings, and planting plans.

Regional resource planning and design, recreation planning and design, urban landscape design, and detail site planning projects involve interdisciplinary involvement between landscape architects, architects, planners, engineers, geographers, physical scientists, social scientists, and others. The relationship between regional or single site qualities of terrain, soil, climate, vegetation, orientation, visual quality, and the program for development are studied carefully to assure sound recommendations.

**Bachelor of Landscape Architecture (B.L.A.) Program**—This 3-year program emphasizes the design process and developing skill in its application. The B.L.A. program is offered jointly by the College of Agriculture and the Institute of Technology. The program is designed to provide the basic professional training for the practice of landscape architecture and to allow for exploration of one or more areas of professional interest. It leads to the professional degree bachelor of landscape architecture.

A total of 230 credits are required for graduation. Of this total, 130 credits are in the upper division. The upper division work includes a sequential design-course program that takes a minimum of 3 years to complete. Students, through consultation with their adviser, select specialized areas of interest in which to concentrate their studies. These areas include: site planning, focusing on developing small-scale

<sup>1</sup>Detailed information about suggested elective programs of study in the following areas of emphasis, as well as other combinations, is available in the Industrial Engineering office, 113 Mechanical Engineering: operations research, quality control and reliability, production engineering, engineering statistics, engineering management.

## Curricular Requirements

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land areas for intensive human use; regional design, focusing on organizing large-scale land areas and analyzing potential in terms of land use; urban design, focusing on the organization of urban environments and systems; and recreational design, focusing on either broad or site aspects of recreational land use. Other areas of interest may be developed.

It is recommended that all students complete a minimum of 800 hours of work 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.

**Bachelor of Environmental Design (B.E.D.) Program**—This nonprofessional program is offered only through the Institute of Technology. It is designed to allow the student to explore a broad range of environmental courses as well as complete 2 years of professional courses in landscape architecture. Upon completion of the B.E.D. degree requirements, a student may continue on for the professional B.L.A. degree, enter a professional master's degree program, or transfer to another discipline such as city design, city and regional planning, or an area of the social or natural sciences.

A total of 192 credits are required for the B.E.D. degree. It is recommended that all students also complete 400 hours of summer work in landscape architecture. Individualized study programs may be arranged with approval of the faculty.

In both degree programs, required core courses must be passed with a minimum grade of C. These courses are: LA 3071, 3072, 5226, 1025, 1026, 3101, 5261, 5263, 5265, 5117, 5118; 5119; Hort 1021, 1022; and all design courses.

## Admission Procedures

To enter the landscape architecture program students must submit an application. Admission to the program is permitted only in the fall quarter unless advanced standing is granted. The deadline for submitting an application is May 1 of the year of desired entry. The procedure and requirements are as follows:

1. Apply to the University of Minnesota if not already a University of Minnesota student. Forms may be obtained from the Office of Admissions, 240 Williamson Hall, 231 Pillsbury Drive S.E., University of Minnesota, Minneapolis, Minnesota 55455; or the Office of Admissions, 130 Coffey Hall, 1420 Eckles Avenue, University of Minnesota, St. Paul, Minnesota 55108.
2. Before an application will be considered, a student must have completed a minimum of 75 credits of required pre-LA courses; courses taken the quarter of current enrollment may be included. This total must include at least 8 credits in basic English or communications, 10 credits in physical and biological sciences, 6 credits in social sciences, 12 credits in studio arts or design, and 8 credits in landscape architectural, environmental, or design theory.
3. Complete the landscape architecture program application form (available from the Department of Horticultural Science and Landscape Architecture, St. Paul; the School of Architecture and Landscape Architecture, Minneapolis; or either Office of Admissions identified above).
4. Submit a letter of intent stating the reasons for selecting landscape architecture as a profession. This letter, generally consisting of one or two pages, should give an account of the student's reason for becoming interested in the field and in becoming a landscape architect, experience in landscape architecture or related fields (art, horticulture, architecture, engineering, construction, etc.), experience or participation in other interests (travel, hobbies, avocations, etc.) and perception of herself or himself in the role of a landscape architect.

5. Submit an official transcript of all college work completed at the University of Minnesota and other colleges to date. Generally, a student must have a 2.50 GPA for admittance.
6. Submit a portfolio of art or design work, environmental or design reports, photographs of sculptural work, slides, or similar examples of creative work. It is suggested that the portfolio be a bound 8½- by 11-inch booklet. A portfolio that is larger than 24 by 36 inches will not be accepted. Material not enclosed in a carrying case is also unacceptable. Any slides must be in an 8½-by 11-inch transparent slide carrier. It is recommended that the student bring the portfolio to the interview with the faculty member.
7. Interview or correspond with at least two landscape architecture faculty members prior to the May 1 application deadline. Specific times for interviews should be arranged with the individual instructors. The interview or correspondence is used to judge the student's commitment to finish the landscape architecture design program and to determine the student's enthusiasm for landscape architecture and sensitivity to people and the environment. It allows the student to demonstrate his or her design, communication, and organizational skills. From the interview the faculty members will judge the student's insight into landscape architecture, maturity, dedication and sincerity, self-confidence, demonstrated design abilities, and self-realization potential.

Applicants are encouraged to visit the design studios and talk to students who are in the program and to find out as much about the profession as they can.

The landscape architecture faculty votes on each applicant. The applicant is either admitted to the program, rejected, or assigned pre-landscape architecture status. Approval for admission is based on consideration of the following:

1. The student's academic standing and grade point average (GPA).
2. The student's maturity and experience.
3. The student's letter of intent.
4. The estimated design potential of the student.
5. The availability of staff and space.

Applicants will be notified by letter of the admission decision not later than June 1. Those admitted must notify the landscape architecture program chair of their intention to attend by July 1, or their place will be forfeited. Those not accepting the opportunity must reapply if they wish to enter the program at a later date.

## BACHELOR OF LANDSCAPE ARCHITECTURE

### LOWER DIVISION (IT and IAg)

Core Course Requirements .....	Credits
Communications:	100
Basic Composition (8) <sup>1</sup>	
Speech (4) <sup>1</sup>	
Writing (4) <sup>1</sup>	
Mathematics (three courses or 11 credits in mathematics, statistics or computer science) <sup>1</sup>	
Physical and Biological Science (18) <sup>1</sup>	
The Individual and Society (16) <sup>1</sup>	
Literary and Artistic Expression (16) <sup>1</sup>	
Studio Arts (12) <sup>1</sup>	
LA 1024 or 1031 (4) <sup>1</sup>	

<sup>1</sup>Courses should be selected, in consultation with the adviser, to complete the Council on Liberal Education requirements specified by each college.

## Curricular Requirements

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Landscape Architecture Theory (select two) (8):

LA 1001

LA 1002

LA 1003

Landscape Architectural History (8)

LA 1021, 1022

Landscape Architecture Technology (7):

AgEn 1400

Soil 1122

Following substantial completion of the above requirements the student must apply for admission to the program before May 1 of the year of desired entry.

### UPPER DIVISION (IT and IAG)

	Credits
Core Course Requirements .....	86
Hort 1021, 1022	
LA 3071, 3072	
LA 3081-3082-3083	
LA 3091-3092-3093	
LA 5110	
LA 5226	
LA 1025	
LA 1026	
LA 3101	
LA 5117, 5118, 5119	
LA 5261, 5263, 5265	
Design Option and Option Support Requirement .....	28
Elective Requirements .....	16

### BACHELOR OF ENVIRONMENTAL DESIGN

#### LOWER DIVISION (IT only)

Core Course Requirements .....	84
Basic Composition (8)	
Math 1211-1221-1231	
Biology and Botany (10)	
Physical Geology (5)	
Physical Geography (5)	
ArtH 1001	
ArtS 1107, 1108, 1109	
LA 1001, 1002, 1003	
LA 1021, 1022, 1023	
Soil 1122	
AgEn 1400 or CE 3100	
Elective Requirements <sup>1</sup> .....	12

Following substantial completion of the above requirements the student must apply for admission to the program before May 1 of the year of desired entry.

#### UPPER DIVISION (IT only)

Core Course Requirements .....	72
Hort 1021, 1022	
LA 1025, 1026, 3101	
LA 3071, 3072, 3075	
LA 3081-3082-3083	
LA 3091-3092-3093	
LA 5117, 5118	
LA 5261, 5263	
Ecology (4) <sup>1</sup>	
Elective Requirements <sup>1</sup> .....	24

<sup>1</sup>Courses should be selected, in consultation with the adviser, to complete the Council on Liberal Education requirements specified by each college.

## 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, a student must complete the minimum liberal education requirements of the Institute of Technology and approved electives. A total of 186 credits are required for the program. The course of study is very flexible and can be adapted to the needs and interests of the individual student. Programs can emphasize diverse goals and fields of interest such as graduate school preparation, applied mathematics, engineering science, computer science, or actuarial science.

The School of Mathematics has a central advising system. Mathematics majors are required to see an adviser at least once a year to plan their programs for the following year. Students are encouraged to develop individualized programs. Advisers are available throughout the academic year, and appointments can be made in 127 Vincent Hall.

### LOWER DIVISION

During their first 2 years, students majoring in mathematics are expected to acquire a knowledge of the following subjects. Requirements may be met by completing the course work listed.

Calculus of Functions of a Single Variable

Math 1211-1221-1231

Math 1311-1321-1331

Math 1611-1621

(or) Math 1511-1521-1531—Honors Calculus

Elementary Computer Programming

CSci 1100 or equivalent

Multivariable Calculus, Linear Algebra and Differential Equations

Math 3511-3521-3531

Math 3211-3221

Math 3211, 3142 and either 3066 or 5521<sup>1</sup>

(or) Math 3611-3621-3631

General Physics

Phys 1271, 1281, 1291

(Students must have completed 1 quarter of calculus before starting this sequence; the associated laboratory courses, Phys 1275, 1285, 1295, are 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, mathematics majors normally complete up to 32 credits of electives during their first 2 years. These electives should include Comp 1001, 1002 and at least 18 credits of the liberal education requirements.

### UPPER DIVISION

All mathematics majors are required to complete 48 credits of mathematics at the 5000 level. The following minimum requirements must be satisfied. Other courses may be used to satisfy the depth requirement (see below) with the adviser's approval.

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 Structures of Algebra

<sup>1</sup>Math 5521 may also be used to satisfy upper division requirements.

## Curricular Requirements

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Depth Requirement—Completion of one of the following sequences:

- 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—Fundamental Structures of 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 5571-5572-5573—Elementary Partial Differential Equations
- Math 5681-5682-5683—Introduction to Probability
- Math 5701-5702-5703—Combinatorics
- Stat 5131-5132-5133—Theory of Statistics, Introduction to Stochastic Processes

Any three 3000- or 5000-level technical courses that form a coherent part of the student's program and require calculus as a prerequisite. *Written approval for these courses must be obtained from one of the central advisers and must be included in the student's file.*

### 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, system dynamics and control, and the production of machinery and consumer products. The mechanical engineer may be engaged in design, development, research, testing, manufacturing, administration, sales engineering, consulting, or education.

The department program is designed to provide the scope and emphasis necessary for a career in mechanical engineering and preparation for graduate work. A strong background in the basic sciences of mathematics, physics, and chemistry, balanced with courses in engineering science and applied engineering, is emphasized. Through electives, each student has an opportunity to develop a program of study that reflects his or her particular area of interest.

**Degree Requirements**—The 4-year curriculum requires 190 quarter credits and leads to the bachelor of mechanical engineering (B.M.E.) degree.

### 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 these two departments are available. Students are encouraged to work with their adviser in formulating a cross-disciplinary program to meet their particular objectives.

The elective program for mechanical engineering consists of a minimum of 28 liberal education elective credits, a coherent program of approximately 24 credits, and 4 free elective credits. Thus the student has the responsibility of selecting 56 credits of course work. Students should work closely with their adviser in planning their elective work. A list of suggested programs is available in 121 Mechanical Engineering (Advising and Information Center) or in 125 Mechanical Engineering. Some of the areas of specialization are listed below:

- Power and Propulsion
- Design and Controls
- Thermodynamics and Heat Transfer
- Materials Engineering
- Environmental Engineering
- Industrial Engineering/Operations Research
- Bioengineering
- Electrical Engineering Emphasis
- Transportation Emphasis
- Solar Energy

## Graduate Study in Mechanical Engineering

A master's degree program in mechanical engineering and industrial engineering is offered by the Institute of Technology. Information about this program is available in the department office, 125 Mechanical Engineering. In addition, M.S. and Ph.D. programs with a major in mechanical or industrial engineering are open to students who meet the entrance requirements of the Graduate School.

## Special Programs in Mechanical Engineering

**Coherent Elective Program**—The coherent elective program in mechanical engineering offers students the opportunity to pursue interdisciplinary study involving several departments as well as the community and industry. Information about this program is available in 121 or 125 Mechanical Engineering. A brief description of a number of the interdisciplinary study opportunities is presented below:

*Bioengineering*—Project work in bioengineering is available. In addition, students can combine elective work in biology, physiology, chemistry, fluid flow, and similar areas with related engineering courses to prepare for work in bioengineering or for graduate study in this area. Students preparing for work in bioengineering may also plan their studies to meet entrance requirements for medical school.

*Transportation*—The program in transportation typically includes work in several departments. Mechanical engineering provides transportation project work involving personalized rapid transit, transportation study and planning, statistical planning, vehicle and system design, community impact studies, and a variety of closely related areas. In addition, propulsion courses relating to vehicle transport as well as a course in urban transportation are offered.

*Environmental Engineering*—The department offers work in environmental engineering with emphasis on air pollution, energy utilization, and emission studies. The environmental engineering staff offers courses in particle technology, air quality and conditioning, contaminant control, and thermal environmental engineering. In addition, the department offers work in propulsion system design, combustion, exhaust emission analysis, and conservation and utilization of energy resources. Environmental work relating to water quality and resources, solid waste disposal, noise pollution, society involvement, and related areas is also available in other departments. Combined programs of study can be planned with the adviser.

*Nuclear Engineering*—An interdisciplinary program in nuclear engineering is available involving course work in the departments of Mechanical Engineering, Chemical Engineering, and Physics.

**Engineering Intern Program**—A mechanical engineering intern program is available during the last 2 years of study. Completion of the major part of the lower division academic curriculum with a satisfactory GPA is required for admission. Application must be made in January of the sophomore year. The program provides applied engineering training in selected established industries during quarters of supervised industrial assignments that alternate with quarters of University studies. Participants register at the University during work periods and are considered regular full-time students.

The B.M.E. degree is awarded upon satisfactory completion of the required mechanical engineering curriculum work as well as 4 quarters of industrial experience. The work assignment credits are considered a part of the coherent elective program requirement.

## Curricular Requirements

Students should contact the director of the engineering intern program for information. Candidates are selected on the basis of scholastic ability, financial need, personal qualifications, and fitness for the work.

**Program in Industrial Engineering/Operations Research**—Engineering training with specialization in industrial engineering is provided by this program. Students in the program may also apply for the engineering intern program in mechanical engineering. For further information, see the Industrial Engineering/Operations Research program description.

**Preparation for Other Programs**—By careful selection of liberal education electives and coherent program electives, the student can prepare for subsequent study in a number of other fields. These include preparation for combined business and engineering work, for law school or for medical school.

## Course Requirements

The lower division program includes course work in basic and engineering science preparatory to the upper division. The upper division program includes additional engineering science and applied engineering subjects such as measurements and design. Additional details, alternate courses, and information about coherent elective programs and areas of specialization are provided in supplemental departmental brochures, which are available in 121 Mechanical Engineering or through the adviser.

### LOWER DIVISION

	Credits
Freshman English or Communication .....	8
Math 1211, 1221, 1231, 3221, ME 3900 <sup>1</sup> —Analysis I, II, III, Linear Algebra and Differential Equations, Engineering Statistics .....	24
Phys 1271, 1281, 1291—General Physics .....	12
Phys 1275, 1285, 1295—General Physics Laboratory .....	3
Chem 1014, MatS 3400 <sup>1</sup> and an additional course in chemistry, biology, ecology, geology, mathematics, or physics .....	12
Introduction to Engineering <sup>1</sup> .....	9
EG 1025—Graphics; CSci 3101—Introduction to FORTRAN Programming; ME 1001—Introduction to Mechanical Engineering .....	18
Engineering Science .....	18
AEM 3036—Dynamics; AEM 3016—Deformable Body Mechanics; EE 3000—Circuits <sup>1</sup> CE 3400 or SMAE 3200—Fluid Mechanics; AEM 1011—Elements: Statics .....	8
Liberal Education Electives (approximately) .....	8
Total Credits .....	94

### UPPER DIVISION

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 .....	
ME 5260—Material Engineering and Processing .....	
ME 5254—Design Morphology With Applications .....	
Laboratory Program .....	8
ME 3701-3702—Basic Measurements Laboratory I, II (4) ME 3703-3704—Advanced Mechanical Engineering Laboratory (4) .....	
Liberal Education Electives (sufficient to complete liberal education requirements) .....	20
Coherent Elective Program <sup>2</sup> .....	24
Open Electives .....	4
Total Credits .....	96

<sup>1</sup>For a complete description of the lower division program, alternate courses, and suggested scheduling, students should obtain the curriculum handout in 121 Mechanical Engineering.

<sup>2</sup>See information about coherent elective programs under the heading "Special Programs in Mechanical Engineering," and obtain the program brochure in 125 or 127 Mechanical Engineering.

## Metallurgy/Materials Science

(Department of Chemical Engineering and Materials Science)

Metallurgists and materials engineers select and develop metals and alloys, ceramics, and plastics to meet diverse engineering needs. These range from extremely small devices such as microelectronic components to large parts such as turbine rotors for electric generating plants. Materials engineers also produce materials for metal and polymer producing industries and test the performance of new products and their component parts.

Professionals in this field are indispensable to virtually every product-related industry, as the following list attests:

<i>Industry/Organization</i>	<i>Metallurgical Engineering Tasks</i>
aircraft	create fatigue, fracture, corrosion, and heat resistant materials for use in products such as landing gear or engine cowling
automotive	develop high strength, heat resistant materials for low emission gas turbine or steam engines
chemical	select and develop materials to hold exotic combinations of temperature and environment in chemical reactors
communication	provide unique semiconductor devices for electronic circuitry
consumer advocates	analyze material failures and recommend solutions for increased product reliability
energy	develop reliable materials for coal gasification or fission reactors as well as unique compounds for energy storage, conversion, and transmission
medical-dental	create and evaluate potential prosthetic materials
nuclear	develop reliable materials for long-term containment of fission and fusion processes
oil and gas	provide basic tools with which the products are extracted and transported
other high technology areas	create new types of metal alloys to circumvent existing time-environment barriers in aerospace and ocean space exploration

The curriculum is based on a foundation of mathematics, physics, and chemistry courses, plus specialized professional courses in areas such as materials science, physical and mechanical metallurgy, thermodynamics, polymer engineering and corrosion, and related laboratory work.

**Degree Requirements**—To receive the bachelor of metallurgical engineering (B.Met.E.) degree, 200 credits are normally required (although the minimum, in special cases, may be 191). Students must complete the IT minimum liberal education requirements (a total of 36 credits including at least 4 in biological science), the pre-metallurgical engineering program (91-100 credits), and a coherent degree program of science and technical courses (91-100 credits).

Suggested lower division and upper division curricula are outlined below. Students, together with an adviser, plan their degree program in two stages: a 1-year plan is submitted at the beginning of the third year, and, ordinarily, a complete 4-year program is submitted for certification by the department by the beginning of the fourth year. Degree programs may emphasize metallurgy or materials science and

## Curricular Requirements

may be oriented toward graduate work or professional employment after graduation. Sample programs are available from advisers or from the departmental office, 151 Chemical Engineering.

**Transfer Students**—Normally, students intending to transfer from another campus or school with lower division standing in general engineering have satisfied most course requirements or have equivalent course work to offer. For specific information, prospective transfer students should write or visit the Department of Chemical Engineering and Materials Science, 151 Chemical Engineering, 421 Washington Avenue S.E., University of Minnesota, Minneapolis, Minnesota 55455. Students can obtain certification of completion of the lower division requirements at the time of transfer.

### 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 1031-1032—General Principles I, II	5	5	...
Chemistry or Approved Technical Electives	...	0-5	4-9
Comp 1001, 1002—Introductory Composition	4	4	...
Liberal Education Electives (quarters of registration may be rearranged with Comp 1001, 1002)	0-4	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 (or biology alternative)	...	4	...
AEM 1002, 3016—Statics and Deformable Body Mechanics	2	...	4
Technical Electives	4-5	...	0-5
Liberal Education Electives	0-4	0-4	4-8
Total Credits, Lower Division Program			95-105

The pre-chemical engineering curriculum also satisfies pre-metallurgical engineering requirements.

Some courses, such as EBB 3101 and GCB 3201 or approved substitutes for them, fulfill both technical and liberal education requirements.

### UPPER DIVISION

#### Third Year

MatS 5011-5012-5013—Introduction to Materials Science	4	4	4
Chem 5534—Statistical Thermodynamics	4	...	...
MatS 5111—Mathematical Methods	3	...	...
MatS 5101, 5102—Thermodynamics and Kinetics	...	4	4
MatS 3501, 3521—Quantitative and X-Ray Metallography	...	3	3
MinE 5910—High Temperature Metallurgical Processes	...	4	...
Technical Electives	4	0-4	4
Liberal Education Electives	...	0-4	0-4

**Fourth Year**

	Credits		
	f	w	s
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	.....	.....
(or) MatS 5630—Polymer Physical Properties .....	.....	.....	4
MatS 5450—Corrosion of Metals .....	.....	.....	.....
(or) Chem 5535—Statistical Mechanics and Reaction Kinetics .....	.....	0-4	0-4
(or) Phys 3501—Modern Physics .....	.....	.....	.....
AEM 5580—Mechanics of Elastic Solids .....	4	.....	.....
(or) ME 5207—Experimental Stress Analysis .....	.....	0-4	0-4
Technical Electives .....	.....	4	.....
Liberal Education Electives .....	4	3-4	3-4
<b>Total Credits Upper Division Program .....</b>	<b>91-100</b>		

**Mineral Engineering**

(Department of Civil and Mineral Engineering)

Production processes in mining involve the development and management of mines, the design of production systems and plants, and economic and technical evaluations of these operations.

Mineral and metal extractive processes include beneficiation of ores and other mineral aggregates (including coal and industrial minerals), extraction of metals from the ores and beneficiated products, and, frequently, purification of the metals produced by these processes. Beneficiation covers such areas as physical processing, chemical processing, size reduction, and gravity, magnetic, and flotation concentration; hydrometallurgy deals with the leaching of ores; pyrometallurgy concerns the high temperature operations of roasting, agglomeration, smelting, and refining.

Mineral resources engineering blends the disciplines of mineral production processes and mineral and metal extraction processes. This field of study is closely allied with geo-engineering.

The undergraduate curriculum includes preparation in basic sciences, engineering, geology, and economics. There is some overlap between the disciplines of mineral production and mineral and metal extraction, since the production engineer and the extractive engineer must be knowledgeable about each other's specialties. Common to both areas of study, for example, is the field of mineral economics, which examines the probability of success or failure of a mineral venture. All courses presented treat the environmental aspects of the mineral industry.

The Mineral Resources Research Center, an integral part of the Department of Civil and Mineral Engineering, has extensive pilot plant and laboratory facilities, which provide a unique opportunity for practical studies in mineral engineering. Its staff members teach many undergraduate courses in mineral processing and extractive metallurgy.

The 4-year curriculum leads to the degree of bachelor of mineral engineering (B.Min.E.). A total of 196 credits are required for graduation. The program includes field trips.

The following program lists the required courses. It can be modified, in consultation with a faculty adviser, to meet the interests of the individual student. The final program must be approved by the Undergraduate Studies Committee for graduation.

*Note:* Courses for which the credits are listed in brackets are for students with a processing interest. Courses for which the credits are listed in parentheses are for students with a production interest.

# Curricular Requirements

## LOWER DIVISION

### First Year

	Credits		
	f	w	s
Math 1211-1221-1231—Analysis I, II, III .....	5	5	5
Chem 1004-1005, 1006—General Chemistry .....	5	5	(4)
Comp 1001-1002—Introductory Composition .....	4	4	...
Phys 1271—General Physics .....	...	...	4
Phys 1275—General Physics Laboratory .....	...	...	1
Liberal Education Electives .....	...	...	(4)
	<u>14</u>	<u>14</u>	<u>14</u>

### Second Year

Math 3221—Introduction to Linear Algebra and Linear Differential Equations .....	5	...	...
Phys 1281-1291—General Physics .....	4	4	...
Phys 1285-1295—General Physics Laboratory .....	1	1	...
AEM 1015—Statics .....	...	4 <sup>1</sup>	...
AEM 3016—Deformable Body Mechanics .....	...	...	4 <sup>1</sup>
Stat 3091 or ME 3900—Statistics .....	...	...	4
CSci 1100—Introduction to FORTRAN Programming .....	...	2	...
CE 3400—Fluid Mechanics .....	...	...	4 <sup>1</sup>
EG 1025—Engineering Graphics .....	4	...	...
Liberal Education Electives .....	<u>4</u>	<u>4</u>	(4)(8)
	<u>18</u>	<u>15</u>	(16)(20)

## UPPER DIVISION—

### MINERAL DEVELOPMENT, PRODUCTION, AND ECONOMICS INTEREST

#### Third Year

MinE 5611, 5612, 5613—Mineral Resources I, II, III .....	4	4	4
MinE 5800, 5810, 5820—Mineral Processing I, II, Principles of Metals Extraction .....	4	4	4
Geo 1111, 3401—Physical Geology, Introductory Mineralogy .....	5	5	...
Geo 3103—Structural and Field Geology .....	...	...	5
CE 3100—Surveying .....	...	...	4
Liberal Education Electives .....	<u>5</u>	<u>4</u>	...
	<u>18</u>	<u>17</u>	<u>17</u>

#### Summer

MinE 5619—Engineering Field Study .....	3	credits	
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#### Fourth Year

MinE 5630—Surface Mining .....	4	...	...
MinE 5720, 5722—Plant Engineering .....	4	4	...
GeoE 5320, 5322—Geomechanics I, II .....	...	4	4
Geo 5351—Metal Sulfide Deposits .....	4	...	...
MinE 5642—Mineral Economics .....	...	3	...
MinE 5650, 5652—Mineral Engineering Design I, II .....	...	4	4
MinE 5700—Systems Analysis .....	...	...	4
MinE 5710—Environmental Aspects of Mineral Engineering .....	...	...	4
GeoE 5437—Computer Applications .....	4	...	...
Liberal Education Electives .....	...	<u>3</u>	...
	<u>16</u>	<u>18</u>	<u>16</u>

<sup>1</sup>These courses are for students with a processing interest. Courses in chemistry, geology, chemical engineering and materials science, and other related fields may be substituted for them.

## UPPER DIVISION—

## MINERAL PROCESSING AND EXTRACTIVE METALLURGY INTEREST

## Third Year

	Credits		
	f	w	s
MinE 5611, 5612, 5613—Mineral Resources I, II, III .....	4	4	4
MinE 5800, 5810, 5820—Mineral Processing I, II, Principles of Metals Extraction .....	4	4	4
Geo 1111, 3401—Physical Geology, Introductory Mineralogy .....	5	5	...
MinE 5825—Metallurgical Heat Transfer .....	...	4	...
MinE 5830—Microscopy for Mineral Engineers .....	...	...	3
EE 3002—Electrical Machinery .....	5	...	...
Liberal Education Electives .....	...	...	7
	18	17	18

## Summer

MinE 5619—Engineering Field Study .....	3	credits
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## Fourth Year

Chem 5520, 5521—Elementary Physical Chemistry .....	3	3	...
MinE 5700—Systems Analysis .....	...	...	4
GeoE 5437—Computer Applications .....	4	...	...
MatS 3400—Mechanical Properties .....	4	...	...
MinE 5650, 5652—Mineral Design I, II .....	...	4	4
MinE 5710—Environmental Aspects of Mineral Engineering .....	...	...	4
MinE 5815—Mineral Processing III .....	...	3	...
MinE 5818—Hydrometallurgy .....	...	...	4
MinE 5910—Metallurgical Unit Processes .....	5	...	...
MinE 5920—Metallurgical Processes .....	...	2	...
Liberal Education Electives .....	...	5	...
	16	17	16

## Physics

(School of Physics and Astronomy)

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 another area such as biology, medicine, law, or business. Students interested in a career as a high school teacher may wish to consider the 4-year program in the College of Education leading to a B.S. degree with a major in physical science. This program leads to teaching licensure. Information about physics programs is available in the undergraduate office, 148 Tate Laboratory of Physics.

Normally, students who fail to earn A or B grades in the freshman mathematics and physics courses will have difficulty pursuing a physics major.

Because of the varied interests of students pursuing this degree program, the required courses have been designed to provide a broad foundation in experimental and theoretical physics. The required courses represent a minimum program, and students preparing for certain careers may want to take more physics courses than are required. Many elective courses are available, and students should consult their adviser or the undergraduate office to plan their program. Sample programs emphasizing various areas of interest are available in the undergraduate office.

## Curricular Requirements

A total of 180 credits are required for the degree. This assumes that the student has satisfied the IT requirement in English composition and has completed 3 years of foreign language study in high school. German, Russian, or French is recommended to fulfill the language requirement.

If a student must complete English composition courses at the University of Minnesota, the number of credits required for graduation may increase by as much as 8 credits.

If a student has not had 3 years of foreign language study in high school, he or she must complete the third quarter of a foreign language at the college level. College-level language courses usually carry 5 credits per quarter, and of those 5 credits, 3 are added to the graduation requirements and 2 may be applied toward the liberal education requirements described below. For a student who must take three language courses (15 credits) at the college level, this means that 9 additional credits are required for graduation and 6 credits are applied toward the liberal education requirements.

To summarize, the number of credits required for graduation can vary as follows:

	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

In the physics curriculum, the English composition credits may not be counted toward the 36 liberal education credits required (see below).

### GENERAL 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 (The Individual and Society), and at least two courses (8-10 credits) must be in category 4 (Literary and Artistic Expression). The remaining courses may be in any category but not in the areas of computer science, mathematics, or the physical sciences. At least two of the courses must be at the 3000 or 5000 level.	
Mathematics .....	
Math 1211-1221-1231 (or) Math 1311-1321-1331 (or) Math 1611-1621 .....	15
Math 3211-3221-3231 (or) Math 3511-3521-3531 (or) Math 3611-3621 .....	10-14
Two additional courses at 5000 level .....	8
Physics .....	
Phys 1271-1281-1291—General Physics .....	12
Phys 1275-1285-1295—General Physics Laboratory .....	3
Phys 3011—Oscillations .....	4
Phys 3015—Laboratory in Oscillations and Waves .....	1
Phys 3201—Thermodynamics or equivalent .....	4
Phys 3511-3512-3513—Modern Physics .....	12
Phys 3515—Modern Physics Laboratory .....	1
Phys 5021-5022—Introduction to Analytic Mechanics .....	8
Phys 5023-5024—Introduction to Electric and Magnetic Fields .....	8
Phys 5101—Introduction to Quantum Mechanics .....	4
Phys 5121-5122-5123—Methods of Experimental Physics .....	13
Electives to total 180 credits .....	<u>37-41</u>
Subtotal .....	180
English and/or Foreign Language as required .....	<u>0-17</u>
Total Credits .....	180-197

### SAMPLE PROGRAM

#### First Year

Phys 1271-1281-1291—General Physics .....	12
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	Credits
Phys 1275-1285-1295—General Physics Laboratory .....	3
(or) Phys 1271-1281—General Physics .....	8
(and) Phys 1275-1285—General Physics Laboratory .....	2
Math 1211-1221-1231—Analysis I, II, III .....	15
English Composition (if required), Foreign Language (if required), and/or Liberal Education Electives .....	15-25
(Students may wish to consider Phys 1071, 1075—Introductory Meteorology, Laboratory or Ast 1021, 1025—Introduction to Astronomy, Laboratory as first-year electives.)	

**Second Year**

Phys 1291, 1295—General Physics, Laboratory (if not completed) .....	5
Phys 3011-3015—Oscillations, Laboratory .....	5
Phys 3201—Thermodynamics .....	4
Phys 3511-3512-3513-3515—Modern Physics, Laboratory .....	13
Math 3211-3221-3231—Analysis IV, Linear Algebra and Differential Equations, Vector Analysis .....	14
Foreign Language (if required) and/or Liberal Education, Technical Electives .....	4-15

**Third Year**

Phys 5021-5022—Classical Mechanics .....	8
Phys 5023-5024—Electricity and Magnetism .....	8
Phys 5121-5122-5123—Methods of Experimental Physics .....	13
Math 5xxx, 5xxx .....	8
Liberal Education, Technical, Physics or Astronomy Electives .....	8-18

**Fourth Year**

Phys 5101—Introduction to Quantum Mechanics .....	4
Physics or Astronomy, Math, Technical, and Liberal Education Electives .....	41-48

Physics or astronomy electives might be selected from, but need not be limited to, the following:

- Ast 3051—Introduction to Astronomy and Astrophysics
- Ast 5161—Astrophysics of Diffuse Matter
- Ast 5162—Astrophysics of Condensed Matter
- Ast 5163—Galactic and Extragalactic Astronomy
- Phys 5031-5032-5033—Topics in Mathematical Physics
- Phys 5102—Introduction to Quantum Mechanics
- Phys 5124—Methods of Experimental Physics: Senior Experimental Project
- Phys 5162—Introduction to Plasma Physics
- Phys 5202-5203—Statistical Mechanics, Transport Theory
- Phys 5231-5232-5233—Introduction to Solid State Physics
- Phys 5301—Introduction to Nuclear Physics
- Phys 5351—Experimental Particle Physics
- Phys 5371—Introduction to Elementary Particle Physics
- Phys 5401—Introduction to Contemporary Problems in Cosmic Ray and Space Physics
- Phys 5441-5442—Introduction to Dynamic Meteorology
- Phys 5451, 5452, 5453—Cloud Physics
- Phys 5461—Physics and Chemistry of the Earth's Upper Atmosphere
- Phys 5551, 5552, 5553—Topics: Physics for Biology and Medicine
- Phys 5801—Modern Optics
- Phys 5805—Contemporary Optics
- Phys 5923, 5924, 5925—History of Physics

**Electives**—The curriculum includes 37 to 41 credits of unspecified electives. Because the specified physics courses represent a minimum requirement, most students will want to take some of their unspecified electives in physics or allied areas.

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

*Electives Suggested for Students Interested in Graduate Study in Physics*

- Continuation of Introduction to Quantum Mechanics (Phys 5102)
- Specialized courses in physics (e.g., nuclear, solid state, elementary particle, plasma, optics)
- Topics in Mathematical Physics (Phys 5031-5032-5033)
- Statistical Mechanics (Phys 5202-5203)
- Methods of Experimental Physics: Senior Experimental Project (Phys 5124)

## Curricular Requirements

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Classical Physics (Phys 5051-5052-5053)  
Quantum Mechanics (Phys 5151-5152-5153)  
Astronomy (Ast 3051, 5161, 5162, 5163)  
Mathematics  
Chemistry  
Computer Programming  
History of Physics

### *Electives Suggested for Students Interested in Industrial Employment or Graduate Study in Engineering*

Methods of Experimental Physics: Senior Experimental Project (Phys 5124)  
Chemistry  
Computer Science  
Specialized courses in physics  
Technical Writing (Comp 3085)  
Electrical Engineering  
Aerospace and Engineering Mechanics (fluid mechanics, elasticity, acoustics)  
Topics in Physics for Biology and Medicine (Phys 5551, 5552, 5553)  
Materials Science  
Geophysics

### *Electives Suggested for Students Interested in Other Professional Schools*

Biology, Dentistry or Medicine  
Topics in Physics for Biology and Medicine (Phys 5551-5552-5553)  
Biology  
Biophysics  
Physiology  
Meteorology  
Meteorology (Phys 1071, 1075, 5441-5442, 5461)  
Cloud Physics (Phys 5451, 5452, 5453)  
Business School  
Computer Programming  
Economics  
Statistics

## Statistics

Statistics deals with methods and theories of data collection, tabulation, and analysis and interpretation, and with the use of data for inference and decision making in industrial, scientific, and governmental enterprises. Students considering professional careers as statisticians should have an aptitude for mathematics and the ability to reason logically. Statistics majors are encouraged to acquire a thorough knowledge in a second academic area such as some branch of engineering or computer science.

The School of Statistics offers a 4-year curriculum leading to the degree bachelor of statistics, B.Stat.

The School of Statistics includes the Department of Applied Statistics and the Department of Theoretical Statistics. While a program may emphasize work in theory or in applications, all programs include some concentration on both theory and applications.

In addition to the prescribed courses listed below, a student must complete the minimum liberal education requirements for the Institute of Technology and approved electives. A total 186 credits are required for the degree. Programs are flexible and can be planned to emphasize such interests as industrial engineering, operations research, computer science, or actuarial science.

Students wishing to plan a program in statistics should make an appointment in 270 Vincent Hall with the director of undergraduate studies.

**LOWER DIVISION**

	Credits
Calculus of a Single Variable	
Math 1211-1221-1231 .....	15
(or) Math 1311-1321-1331 .....	15
(or) Math 1611-1621 .....	10
Elements of Computer Programming	
CSci 1100-1101 .....	4
(or) CSci 3101 .....	4
Multivariable Calculus, Linear Algebra	
Math 3511-3521 .....	9
(or) Math 3211, and 3221 or 3142 .....	9 or 10
(or) Math 3611-3621 .....	10
Physics and Chemistry	
Phys 1271-1275-1281-1285-1291-1295 .....	15
Chem 1014 .....	4
Statistics	
Stat 3091 .....	4

**UPPER DIVISION**

Stat 5021-5022—Statistical Analysis .....	10
Stat 5131-5132-5133—Theory .....	12
Stat 5302—Applied Regression .....	4
Statistics Electives—12 credits chosen from:	
Stat 5201—Sampling Methodology in Finite Populations .....	4
(or) QA 5171—Statistical Methods for Sample Surveys .....	4
Stat 5301—Designing Experiments .....	4
(or) IEOR 5550-5551—Design and Analysis of Experiments .....	8
Stat 5401—Introduction to Multivariate Methods .....	4
Stat 5421—Analysis of Categorical Data .....	4
Stat 5601—Nonparametric Methods .....	4
IEOR 5531—Industrial Sampling Techniques .....	4
Technical Electives	
20 credits of adviser approved, 5000-level technical courses that form a coherent program in statistics and related areas; e.g., computer science, mathematics, industrial engineering, operations research, management science. The following courses are suggested:	
CSci 5001—Linear Programming Algorithms .....	4
CSci 5002—Nonlinear Programming .....	4
CSci 5101-5102—Structure and Programming of Software Systems .....	8
CSci 5104—System Simulation .....	4
CSci 5301-5302—Numerical Analysis .....	8
EE 5702—Stochastic Processes and Optimum Filtering .....	3
IEOR 5000—Industrial Engineering Analysis .....	4
IEOR 5010—Work Analysis .....	4
IEOR 5030—Quality Control and Reliability .....	4
IEOR 5040, 5441-5442—Operations Research .....	12
IEOR 5361—Inventory and Production Control .....	4
Math 5612-5613-5614—Analysis .....	12
Math 5681-5682-5683—Probability .....	12

## IV. COURSE LISTINGS

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

- \* Courses in which graduate students may prepare Plan B projects.
- † All the courses preceding the dagger must be completed before credit will be granted for any quarter of the sequence.
- § Credit will not be granted if the equivalent course listed after this section mark has been taken for credit.
- ¶ Concurrent registration is allowed (or required) in the course listed after the paragraph mark.
- # Consent of the instructor is required prior to registration.
- Δ Consent of division, department, or school offering course is required prior to registration.
- H Honors section of a regular course.
- f,w,s,su Following a course number indicate fall, winter, spring, or summer quarters.

A hyphen between course numbers (e.g., 3142-3143-3144) indicates a sequence of courses that must be taken in the order listed.

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

Courses numbered 8000 or above are open to graduate students only, except by special permission of the dean of the Graduate School.

If a course prerequisite statement specifies a class rank (e.g., 3rd year), no one below that rank may register for the course without special permission from the Scholastic Standards Committee.

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

### Special Interest Courses for IT Students

**EBB 3101. ECOLOGY FOR ENGINEERS AND PHYSICAL SCIENTISTS.** (4 cr, §1003, §3001, §Biol 1104; not open to biology majors; prereq Math 1231)

The scientific basis for the past and continued existence of life on the earth.

**Engl 3085. TECHNICAL WRITING FOR ENGINEERS.** (4 cr; prereq completion of freshman English)

Theory and practice in technical and professional writing.

**IoIT 1040H. HONORS SEMINAR.** (1 cr per qtr; prereq admission to IT honors program or Δ; 2 rec hrs per wk)

Discussions of topics of current interest, visits to places of scientific or technological interest in the Twin Cities area.

**IoIT 1222. CAREER PLANNING AND OCCUPATIONAL CHOICE.** (2 cr; 2 hrs per wk)

Opportunity to learn how to make vocational decisions, gather information about technical careers, become acquainted with the world of work, and assess personal skills, interests, and values.

**IoIT 3222. WOMEN AND CAREERS IN TRADITIONALLY MALE FIELDS.** (1 cr; 2 lect hrs per wk)

Information about women and careers in medicine, engineering, biological sciences, law, physical sciences, business management, mathematics-computer science, and architecture. Status of women in these fields from early 1900s to present. Guest lectures by women professionals. Life-style alternatives for women with careers.

**IoIT 3305a. THE SOCIAL AND PROFESSIONAL RESPONSIBILITIES OF THE ENGINEER.** (2 or 4 cr; prereq jr standing)

Ethical problems arising from the engineer's responsibility to the public, to clients, and to other professionals are explored in a series of dialogues between practicing engineers and lay persons. Topics include environmental protection, professional employer/employee obligations, professional registration, industrial safety, and liability.

**SSci 3402. ECOLOGY, TECHNOLOGY, AND SOCIETY.** (4 cr)

The impact of technology on society as seen by engineers, scientists, and social scientists. 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.

## Aerospace Engineering and Mechanics (AEM)

- 1001. AEROSPACE ENGINEERING ORIENTATION.** (1 cr; prereq 1st-qr fr 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.
- 1011. ELEMENTS OF STATICS.** (2 cr; no cr for CE majors; prereq Phys 1271; 1 lect and 2 rec hrs per wk)  
Force vectors, resultants, components; particle equilibrium. Moments of forces; the couple. Mechanical systems and the free-body diagram. Equilibrium equations for the rigid body and simple trusses and frames. Coulomb friction.
- 1015. STATICS.** (4 cr, §1011; prereq Phys 1271, Math 1231)  
Force and moment vectors; resultants. Principles of statics. Applications to simple trusses, frames, and machines. Distributed loads. Hydrostatics. Properties of areas. Laws of friction.
- 3016. DEFORMABLE BODY MECHANICS.** (4 cr; prereq 1011 or 1015, §Math 3221)  
Uniaxial loading and deformation. Stress and strain at a point. Forces and moments in beams. Centroids and second moments. Material behavior; linear elasticity. Torsion. Bending of beams of symmetrical section.
- 3036. DYNAMICS.** (4 cr; prereq 1011 or 1015, §Math 3221)  
Review of particle dynamics. Mechanical systems and the rigid-body model. Kinematics and dynamics of plane systems.
- 3092. STATICS AND MECHANICS OF MATERIALS I.** (4 cr; prereq Math 1231, Phys 1121)  
Forces, equilibrium, and free-body diagrams. Analysis of statically determinate plane trusses and frames. Bending of statically determinate beams. Bending stress and shear stress in beams.
- 3093. STATICS AND MECHANICS OF MATERIALS II.** (4 cr; prereq 3092; includes lab period per wk)  
Statically indeterminate problems in axial force and beam bending. The three-moment principle for continuous beams. Combined direct and bending stresses. Column buckling. Laboratory tests of mechanical properties of construction materials and of simple structural configurations.
- 3401. INTRODUCTION TO DYNAMICAL SYSTEMS.** (4 cr, §ME 3201; prereq 3036)  
Mathematical modeling of mechanical, hydraulic, and electromechanical systems; Laplace transforms, transfer functions and block diagrams, response of free and forced systems, elementary concepts in feedback control, frequency response.
- 5200. KINEMATICS AND DYNAMICS OF FLUID FLOW.** (4 cr, §CE 3400; prereq mathematics through differential equations and linear algebra; 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 and Stokes theorems to fluid flow. Flow about cylinder. Potential flow in two and three dimensions. Dynamics, Euler equation, Bernoulli 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 #)  
Irrational, 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.
- 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.

## Course Listings

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- 5242. ONE-DIMENSIONAL GAS DYNAMICS.** (4 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.
- 5250. COMPUTATIONAL FLUID MECHANICS.** (4 cr; prereq 5201, 5202 or # . . . CSci 1101 or 3101)  
Methods for solving practical problems in fluid mechanics that require use of large high speed computers. Emphasis on utilization of methods and results rather than on mathematical analysis.
- 5270. ATMOSPHERIC FLUID DYNAMICS.** (4 cr; prereq some background in viscous flow, such as 5202 or #)  
The large- and small-scale motions, structure, and physical mechanisms of our atmospheric environment.
- 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 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 3401 and 5206)  
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. Routh discriminant. Aerospace vehicle working equations and solutions. Vehicle response to control actions.
- 5321. AUTOMATIC FLIGHT CONTROL SYSTEMS.** (4 cr; prereq 3401, 5300 or equiv or #)  
Analysis and synthesis of automatic flight control systems for aerospace vehicles, longitudinal and lateral autopilots, gain scheduling, control of inertial cross-coupling.
- 5330, 5331. DESIGN OF AEROSPACE ELEMENTS AND SYSTEMS.** (4 cr per qtr; prereq 4th-yr engineering major and #)  
*Interdisciplinary projects with students from other departments.*
- 5359. DECELERATION OF AEROSPACE CRAFT.** (4 cr; prereq 3036, 5200)  
Aircraft approach and landing run with parachutes, reverse pitch propellers and jet thrust reversers. Terrestrial and reentry trajectories. Systems for aerial delivery and space recovery. Aircraft antispin parachutes. Aerodynamic characteristics of parachutes. Screen drag of porous sheets as function of Reynolds and Mach numbers. Interaction between screen drag and aerodynamic characteristics of parachutes.
- 5360. DYNAMICS OF AEROSPACE RECOVERY SYSTEMS.** (4 cr; prereq 3036 and 5200)  
Exact and approximate reentry trajectories. Dynamics and aerodynamics of decelerator deployment and activation. Layout and sequencing of multistage recovery systems for airplanes, airborne and space objects, and shuttle aircraft. Dynamic stability of load-parachute systems.
- 5370, 5371. AERODYNAMICS OF V/STOL FLIGHT.** (4 cr per qtr; prereq 5206)  
Aerodynamic characteristics of the classical rotor. Combinations of rotor-wing and direct thrust-wing configurations are analyzed for high-speed V/STOL aircraft. Jet flap, boundary layer control, and ground effect machines.
- 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.
- 5435. INTRODUCTION TO RANDOM VIBRATION THEORY.** (3 cr lect, 1 cr lab; prereq 3036 or #)  
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, 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 equations, application of Lagrange equations to systems of technological interest.

## Aerospace Engineering and Mechanics

- 5440. INTERMEDIATE DYNAMICAL SYSTEMS.** (4 cr; prereq 3401)  
Modeling of multi-degree-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 or equiv; 3 lect, 2 problem sessions per wk)  
Elastic analysis of components important to aerospace structures. Energy methods for trusses and beams, thermal stresses, plane stress with circular symmetry, composite materials, torsion and bending of thin walled structures, plate bending with circular symmetry, elastic stability of plates and beams, matrix methods.
- 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.
- 5570. MECHANICS OF BIOMATERIALS.** (4 cr; prereq #)  
Mechanical behavior of metallic systems for implants. Criterion of strength and application of ceramic implants. Other relevant properties of implants. Mechanics of polymers, especially viscoelastic behavior. Principles of fiber reinforcements and rational design of composites. Stress analysis of natural and manufactured material systems.
- 5580. INTRODUCTION TO THE MECHANICS OF SOLIDS.** (4 cr; prereq 3016 or #)  
Linear theory of strain and stress in two dimensions. Stress-strain relations (plane stress) for elastic and perfectly plastic materials. Plane-stress beam solutions; St. Venant principle. Rotationally symmetric solutions in plane stress. Three-dimensional strain, stress, and constitutive relations. Simple exact solutions. Plane stress and plane strain as three-dimensional problems.
- 5581. MECHANICS OF ELASTIC SOLIDS.** (4 cr; prereq 5580)  
Torsion of cylindrical and prismatic bars. Minimum potential and complementary energy theorems, with applications. Bending of plates. Thermoelasticity. Waves and vibrations.
- 5582. ENERGY METHODS IN SOLIDS.** (4 cr; prereq 5580)  
Principle of virtual work. Minimum principles for elastic and perfectly plastic solids. Applications of theorems to bars, beams, plates, etc. Variational techniques. Finite element models. Approximate methods of solution for practical problems.
- 5584. MECHANICS OF VISCOELASTIC SOLIDS.** (4 cr; prereq 5580)  
Viscoelasticity, creep, and relaxation. Linear viscoelasticity. Quasi-static stress analysis. Correspondence principles. Thermal influence. Dynamical problems. Energy storage and loss.
- 5585. MECHANICS OF PERFECTLY PLASTIC SOLIDS.** (4 cr; prereq 5580)  
Elastic plastic and rigid plastic models. Bending of beams and simple frames. Arches. Circular plates in bending. Torsion of cylindrical and prismatic bars. Combined tension and torsion of circular cylindrical bars. Plane strain forming processes.
- 5642. ELEMENTARY AEROMECHANICS LABORATORY.** (2 cr; prereq 5200 or equiv, 3016; 2 hrs per wk)  
Basic measurement techniques in aeromechanics. Material properties, manometers, Pitot tubes, strain gages. Simple experiments illustrating basic principles of aeromechanics.
- 5645, 5646. AEROMECHANICS LABORATORY I, II.** (2 cr per qtr; prereq 3016, 5200; 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.
- 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.
- 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, acoustical 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.

## Course Listings

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- 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 consent of faculty sponsor 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 consent of faculty sponsor 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 #)  
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.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

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

#### 8201. FOUNDATIONS OF FLUID MECHANICS

#### 8202. VISCOUS FLOW

#### 8203. INVISCID INCOMPRESSIBLE FLOW

#### 8204. COMPRESSIBLE FLOW

#### 8207. STABILITY OF FLUID MOTIONS I

#### 8208. STABILITY OF FLUID MOTIONS II

#### 8209. ROTATING FLUIDS

#### 8216, 8217. THEORY OF TURBULENCE I, II

#### 8220. RHEOLOGICAL FLUID MECHANICS I

#### 8221. RHEOLOGICAL FLUID MECHANICS II

#### 8230. ADVANCED GAS DYNAMICS

#### 8240. PERTURBATION METHODS IN FLUID MECHANICS

#### 8260-8261. NONLINEAR WAVES IN MECHANICS I, II

#### 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. THEORY OF PLASTICITY

#### 8523. SPECIAL TOPICS IN PLASTICITY

#### 8527. THEORY OF ELASTIC STABILITY

#### 8540. VISCOELASTICITY

#### 8541-8542. THEORY OF VISCOELASTICITY

#### 8570. FRACTURE MECHANICS

#### 8585, 8586, 8587. ADVANCED TOPICS IN CONTINUUM MECHANICS

#### 8590. THEORY OF PLATES AND SHELLS

#### 8594. ELASTOSTATICS I

#### 8595. ELASTOSTATICS II

#### 8596. ELASTODYNAMICS

- 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)**

- 1031. **COMPUTATIONS IN AGRICULTURAL ENGINEERING.** (2 cr; prereq 1030 or CSci 1100, Math 1211 or 1142; 1 lect and 2 rec hrs per wk)  
Introduction to problems in agricultural engineering. Elementary numerical and computational techniques. Applications involving FORTRAN programming.
- 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. Professional opportunities and responsibilities.
- 1071. **INTRODUCTION TO AGRICULTURAL ENGINEERING.** (2 cr; prereq Math 1211 or 1142; 1 lect and 3 lab hrs per wk)  
Analysis of elementary agricultural engineering problems. Introduction to design including problem formulation, analysis, synthesis, evaluation, and specification.
- 3050. **SOIL-PLANT RELATIONS IN AGRICULTURAL ENGINEERING.** (3 cr; prereq  $\S$ Soil 3049, AEM 3016 or  $\S$ AEM 3016; 3 lect and 3 lab hrs per wk for 7 wks)  
Soil-plant environment. Interrelation with engineering and management requirements. Growth processes, limiting factors. Mechanical and hydraulic properties of soils.
- 3052. **PHYSIO-ENGINEERING IN AGRICULTURE.** (4 cr; prereq AEM 3016 or  $\S$ AEM 3016; 3 lect and 3 lab hrs per wk)  
Mechanical and hydraulic properties of porous media, moisture relations; strength parameters for structural and mechanical design. Soil-machine action involved in tillage and traction. Energy and water balance in the soil-plant system. Plant structure and growth. Engineering and management requirements.
- 3060. **ANALYSIS IN AGRICULTURAL ENGINEERING.** (4 cr; prereq 1031, Math 3211; 4 lect hrs per wk)  
Introduction to probability. Normal and other frequency distributions. Elementary statistics with applications to problems in agricultural engineering. Engineering economics and benefit cost analysis.
- 3970. **DIRECTED STUDIES IN AGRICULTURAL ENGINEERING.** (Cr ar)  
Independent study of topic(s) involving physical principles as applied to agricultural production and land resources.
- 5050. **INTERN REPORTS.** (1 cr per qtr)  
Required of students in the engineering intern program during the employment periods.
- 5060. **PROCESSING.** (4 cr; prereq 3050, ME 5342; 3 lect and 3 lab hrs per wk)  
Size reduction, cleaning, and conveying of agricultural products. Properties of air, water vapors, 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 3060, 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.
- 5072. **FINITE ELEMENT METHOD: FUNDAMENTALS AND APPLICATIONS.** (4 cr; prereq differential equations and sr status or #; 4 lect hrs per wk)  
Basic theory and principles of implementation of the finite element method for a number of fundamental engineering areas. Applications in heat transfer, fluid mechanics, solid mechanics, radial and axisymmetric field problems, and time-dependent field problems.
- 5081, 5082, 5083, 5084. **DESIGN.** (4 cr per qtr; prereq 3050, 3060; 1 lect and 6 lab hrs per wk)  
An engineering design project in the student's interest area(s), 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  $\S$ 5060 or #; 4 lect hrs per wk)  
Fundamental requirements for handling food products. Separation processes in the food industry. Dehydration and storage of foods.

## Course Listings

- 5140. FOOD ENGINEERING II.** (4 cr; prereq FScN 5120, 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.
- 5191-5192. SPECIAL PROBLEMS IN AGRICULTURAL ENGINEERING.** (2-5 cr per qtr; prereq #)  
Individual study project in agricultural engineering at advanced level. Application of engineering principles to a specific problem.
- 5330. AGRICULTURAL MACHINERY.** (4 cr; prereq ME 3203 and knowledge of actions of agricultural mechanisms, #; 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 ME 3303; 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.
- 5540. EROSION CONTROL, WATERSHED ENGINEERING.** (4 cr; prereq 3050 or CE 3300, CE 5401 or #; 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 or CE 3300, CE 5401 or #; 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.
- 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. Determinate analysis and indeterminate concepts. Computer-aided design.
- 5740. ENVIRONMENTAL CONTROL FOR AGRICULTURAL PRODUCTION.** (4 cr; prereq 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 prediction of environmental conditions.
- 5910. AGRICULTURAL WASTE MANAGEMENT ENGINEERING I.** (4 cr; prereq 3050, Chem 1005 or 1014 or #; 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.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 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)  
Interaction of human beings and their environment using the disciplines of the natural and social sciences and the arts as resource background for readings, lectures, discussions, and workshop sessions.
- 1002w. ENVIRONMENTAL DESIGN: TOOLS AND PROCESSES.** (4 cr, §LA 1002; prereq 1001)  
The nature and effects of various tools and processes of environmental change ranging from buildings and landscapes to economic policies, climate, and myths. Readings, lectures, discussions, 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.
- 1010. INTRODUCTION TO ARCHITECTURE, DRAWING.** (4 cr; 8 lab hrs per wk)  
Basic drawing techniques, freehand drawing and sketching, perspective, shades, and shadows.
- 1021f. HISTORY OF ENVIRONMENTAL DEVELOPMENT: ARCHITECTURE AND LANDSCAPE ARCHITECTURE.** (4 cr, §LA 1021; 4 lect hrs per wk)  
Introduction to the philosophy and principles of architecture and landscape architecture as an art; survey of environmental history from the ancient periods through the medieval age.
- 1022w. HISTORY OF ENVIRONMENTAL DEVELOPMENT: ARCHITECTURE AND LANDSCAPE ARCHITECTURE.** (4 cr, §LA 1022; 4 lect hrs per wk)  
Continuation of Arch 1021 from the Renaissance through the modern eras; focuses on forces and individuals that shaped the form of architecture and landscape architecture in the 19th and 20th centuries in America and Europe.
- 1023s. HISTORY OF ENVIRONMENTAL DEVELOPMENT: PLANNING.** (4 cr, §LA 1023; prereq 1022; 4 lect hrs per wk)  
Introduction to urban planning. Survey of the 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. ARCHITECTURAL GRAPHICS.** (2 cr per qtr; restricted to students in pre-architecture and architecture; 2½ lab hrs per wk)  
The skills, media, and techniques of architectural graphics communication, including perspective systems, shade and shadow, color, freehand drawing, and organizing presentation material.
- 3061-3062. BUILDING SYSTEMS.** (5 cr per qtr; prereq Arch 3083; 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 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 Δ; 18 lab hrs per wk)  
Perceptual and conceptual aspects of the physical environment. Fundamentals of architectural design and design methodology. Architectural drawing. Model making.
- 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 classical 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 1800.
- 5056. MODERN ARCHITECTURE.** (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)  
History of development of architecture and urban design in Europe and America from early 19th century until World War II.

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- 5057. ASIAN ARCHITECTURE.** (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)  
Selected topics from the history of architecture and urban design in West, South, and East Asia.
- 5061. LATE MODERN ARCHITECTURE.** (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)  
Developments, theories, and stylistic movements in architecture from World War II to the present time.
- 5101, 5102, 5103. TUTORIAL WORK IN HISTORY OF ARCHITECTURE.** (Cr ar; prereq 5056 or #; 1 conf and 5 research hrs per wk)  
Reading and written reports on special historical problems.
- 5104. SEMINAR: EUROPEAN ARCHITECTURE.** (4 cr; prereq 5056 or #; 4 seminar hrs per wk)  
Contemporary architecture from the beginning of modern movement until the present time with emphasis on 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.** (4 cr; prereq 5056 or #; 4 seminar hrs per wk)  
Survey of Scandinavian architectural history with emphasis on the origin and development of modern architecture in Denmark, Finland, Norway, and Sweden.
- 5106. SEMINAR: AMERICAN ARCHITECTURE.** (4 cr; prereq 5056 or #; 4 seminar hrs per wk)  
Contemporary architecture in the United States from the period of Henry Hobson Richardson until the present time and including the 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; 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 studied 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 writing 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.
- 5127, 5128. LAW FOR ARCHITECTS.** (4 cr per qtr; prereq 3093 or Δ; 2 lect hrs per wk)  
Legal subject matter relevant to the work of architects and design professionals.
- 5129. LAW FOR ARCHITECTS SEMINAR.** (4 cr; prereq 3093 and 5128 or #; 4 hrs per wk)  
Third course in series. Case studies of legal subject matter relevant to the work of architects and design professionals; individual research assignments.
- 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.
- 5137. PLANNING: URBAN FUNCTION AND STRUCTURE.** (4 cr; prereq #)  
Economic, technological, and social factors that 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 the 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, 5153. **THEORY OF ARCHITECTURE.** (2 cr per qtr; prereq #)  
Architecture as seen in a philosophical and theoretical context
5155. **URBAN DEVELOPMENT PROCESS.** (3 cr; prereq #)  
History of urban development programs in the United States including urban renewal, new communities and community development, review of relevant legislation; economics and politics of the urban development process.
5156. **URBAN DEVELOPMENT PROCESS.** (3 cr; prereq #)  
Comparative study of major urban development projects drawing upon American and European experience. The process through which development projects are planned and carried out.
5170. **CITYSCAPE.** (3 cr; prereq 3093 or #: hrs ar)  
The city and its components as aesthetic elements. Factors that 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.
5950. **TOPICS IN ARCHITECTURE.** (Cr ar; prereq 3093 and 3067 or #)  
Special topics of concern to the field.
5970. **DIRECTED STUDIES.** (Cr ar; prereq #)  
Areas of study useful to individual program objectives but not available in regular course offerings.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 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.** (4 cr, §1021; 4 lect hrs per wk)  
The sun, the moon, the planets and their motions, stars and stellar systems, galaxies and cosmology. Nonmathematical.
1015. **DESCRIPTIVE ASTRONOMY LABORATORY.** (1 cr, §1025; S-N only; 1 lab hr per wk)  
Laboratory offered in conjunction with 1011. Only opportunity to observe with telescope.
1021. **INTRODUCTION TO ASTRONOMY.** (4 cr, §1011; prereq high school trigonometry and physics or chemistry; 4 lect hrs per wk)  
Solar system, stars, galaxies, and cosmology. A more mathematical and physical discussion than 1011.
1025. **INTRODUCTION TO ASTRONOMY LABORATORY.** (1 cr, §1015; S-N only; 1 lab hr per wk)  
Laboratory offered in conjunction with 1021. Only opportunity to observe with telescope.
1201. **TOPICS IN MODERN ASTROPHYSICS.** (4 cr; prereq 1011 or 1021 or equiv, #)  
Current research problems in astronomy and astrophysics. Discussion and participation by class members. Nonmathematical.
3051. **INTRODUCTION TO ASTRONOMY AND ASTROPHYSICS.** (4 cr; prereq 1 yr calculus and Phys 1106 or 1291 or #)  
The solar system, stellar systems, galaxies and extragalactic universe. How information is obtained, conclusions that can be inferred from observations through applications of elementary physics to astronomical problems.
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 #)  
Luminosities, temperatures, masses, and densities of stars; their mechanisms for energy generation. Chemical composition of stars and the probable course of stellar evolution.

## Course Listings

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- 5163. GALACTIC AND EXTRAGALACTIC ASTRONOMY.** (4 cr; prereq 3051 and Phys 3511 or #)  
The Milky Way, physical properties of galaxies, distance scale, distance-red-shift relation, clusters of galaxies, peculiar galaxies, radio galaxies and quasars, cosmology.
- 5970. DIRECTED STUDIES.** (1-5 cr; prereq #,  $\Delta$ )  
Independent, directed study in observational and theoretical astrophysics in areas arranged by the student with a faculty member. Primarily intended for senior astrophysics majors.
- 5990. DIRECTED RESEARCH.** (3 cr minimum; prereq #,  $\Delta$ )  
Independent research in observational or theoretical astrophysics under the direction of a faculty member. Intended for senior astrophysics majors.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8200.\* SEMINAR: ASTROPHYSICS AND SPACE PHYSICS**
- 8481-8482-8483.\* ASTROPHYSICS**
- 8990. RESEARCH IN ASTRONOMY AND ASTROPHYSICS**
- Phys 8081-8082.\* GENERAL RELATIVITY**
- Phys 8163-8164.\* PLASMA PHYSICS**
- Phys 8411-8412.\* COSMIC RAY AND SPACE PHYSICS**
- Phys 8421-8422.\* MAGNETOSPHERIC PHYSICS**
- Phys 8484.\* ORIGIN AND EVOLUTION OF THE SOLAR SYSTEM**

## 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 5101; 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; prereq 5101, Chem 5534 or #; 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.** (4 cr; prereq 5501 or #; 3 lect and 2 design lab hrs per wk)  
(Continuation of 5501) Computer-aided design of unit operations, chemical reactors and integrated plants; operability characteristics of chemical processes; design for optimum operability (safety, reliability, control).

- 5601. PROCESS CONTROL.** (4 cr; prereq 4th yr or #; 3 lect and 2 rec hrs per wk)  
Elementary theory of control and its application to chemical processes. Synthesis of feedback control loops for linear systems.
- 5603. PROCESS CONTROL.** (3 cr; prereq 5601 or #; 3 lect hrs per wk)  
Advanced topics in chemical process control; synthesis of control structures; multivariable control schemes, optimal control and estimation; computer-aided real-time process control.
- 5604. PROCESS CONTROL LABORATORY.** (2 cr; prereq 5601)  
Experiments designed to illustrate and apply control theory. Measurement techniques, calibration, tuning of controls, characterization of sensors and control circuits.
- 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  
Modeling and analysis of biosystems. Thermodynamics, transport and transfer, biochemical reactions, growth and death processes 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.
- 5757. PRINCIPLES OF ARTIFICIAL INTERNAL ORGAN DESIGN.** (3 cr; prereq #: 3 lect hrs per wk) Keller  
Survey of those artificial internal organs important in the maintenance of homeostasis with emphasis on the general principles and particular problems involved in their design, including blood compatibility, access, and alternative approaches to replacing natural organ functions.
- 5761. FLOW OF FLUIDS IN POROUS MEDIA WITH APPLICATIONS TO OIL RECOVERY.** (3 cr; 3 lect hrs per wk) Davis, Scriven  
Survey of fluid mechanics, interfacial phenomena, transport processes, and statistical aspects, with application to petroleum production and chemical and thermal processes of enhanced recovery.
- 5801. AIR POLLUTION CONTROL ENGINEERING.** (4 cr; 4 lect hrs per wk)  
Analysis and design of equipment used to reduce emission of gases and particulates. Methods for controlling air pollution.
- 5901. CHEMICAL PROCESS LABORATORY.** (2 cr; prereq 5301)  
Applications of kinetics and heat and mass transfer to batch and continuous flow reactors.
- 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

(For course descriptions, see the *Graduate School Bulletin*)

- 8004. PHYSICAL RATE PROCESSES**
- 8005. PHYSICAL RATE PROCESSES**
- 8101. INTERMEDIATE FLUID MECHANICS**
- 8102. PROBLEMS IN FLUID MECHANICS**
- 8103. TENSORS AND FIELD THEORY WITH APPLICATIONS**
- 8104. INTERFACES AND INTERFACIAL PHENOMENA**
- 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. PHYSICAL AND CHEMICAL 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**

## Course Listings

8601-8602-8603. MOLECULAR THEORY OF EQUILIBRIUM AND NONEQUILIBRIUM PROCESSES

8701. ANALYSIS OF CHEMICAL ENGINEERING PROBLEMS

8702. ADVANCED TOPICS IN CHEMICAL ENGINEERING

8750. ADVANCED CHEMICAL PROCESS DESIGN

8801-8802-8803. SEMINAR

8850. GENERAL SURVEY OF CHEMICAL ENGINEERING

8901, 8902, 8903. RESEARCH IN CHEMICAL ENGINEERING

## Chemistry (Chem)

**For Students Taking a Beginning Course in Chemistry**—All courses offered are intended for students who have had high school chemistry. Although students without high school chemistry are permitted to enroll in Chem 1001, 1004, and 1014, the majority of students in these courses have taken high school chemistry. Students without this high school background will be at a great disadvantage.

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

**1000. PHYSICAL WORLD, CHEMISTRY.** (4 cr, §any other college chemistry course; prereq 1 yr high school algebra high school chemistry recommended, a terminal course cannot be used as prereq for any other advanced chemistry course)

Fundamental concepts of chemical bonding, structure of matter, and forces in the physical world. Scientific methods and principles that contribute to understanding the environment and problems faced in improving it.

**1001-1002†. CHEMICAL PRINCIPLES AND COVALENT SYSTEMS.** (See *CLA Bulletin*)

**1003. PHYSICAL WORLD, CHEMISTRY.** (5 cr, §any other college chemistry course; prereq 1 yr high school algebra high school chemistry recommended, a terminal course cannot be used as prereq for any other advanced chemistry course, 4 lect, 1 rec, 1 2-hr lab per wk)

Fundamental concepts of chemical bonding, structure of matter, and forces in the physical world. Scientific methods and principles contribute to understanding of the environment and problems faced in improving it. Labs to illustrate.

**1004-1005†. GENERAL PRINCIPLES OF CHEMISTRY.** (5 cr per qtr, §1000, §1001-1002, §1014, §1031-1032; primarily for non-chemistry majors; prereq placement index of Y or predicted mathematics GPA of 1.90 on ACT, Math 0009 or college course in algebra; 4 yrs high school mathematics; high school chemistry and physics recommended; beginning in fall 1981 high school chemistry will be required; 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; lab fee required)

The chemistry of selected cations and anions. Spectrophotometric, potentiometric, and chromatographic detection methods. Metal ion studies include systematics; acid-base principles; influence on the environment; importance in biological systems; formation and stereochemistry of complexes. Lecture and laboratory.

**1014. CONCEPTS OF CHEMISTRY.** (4 cr, §1000, §1001, §1003, §1004, §1031; primarily for engineering majors; sophs and above; prereq Phys 1105 or 1281 or #; 4 lect hrs per wk)

Fundamental principles of chemistry. A terminal course.

**1031-1032†. CHEMICAL PRINCIPLES I AND II.** (5 cr, §1000, §1001-1002, §1003, §1004-1005, §1014; prereq chemistry or chemical engineering major or #; 4 yrs high school mathematics, 1 yr high school chemistry and 1 yr high school physics recommended; beginning in fall 1981 high school chemistry will be required; 3 lect, 1 lect discussion, 1 lab discussion, one 4-hr lab per wk)

Stoichiometry, development and use of structural concepts, energetics, geometry of molecules, bonding, and the behavior of the gaseous and liquid states, the solid state, theory of solutions, equilibrium, gas and condensed phases, behavior and nature of the solution process, acids and bases.

**1133. ELEMENTARY QUANTITATIVE ANALYSIS.** (5 cr, prereq 1032; 3 lect and two 4-hr labs per wk)

An introduction to the theory and practice of chemical methods of analysis.

- 3100. QUANTITATIVE ANALYSIS LECTURE.** (3 cr, 3100-3101†; for non-chemistry majors; prereq 1005 or 1032)  
Introduction to the theory of quantitative chemical analysis. Modern quantitative methods of analysis. Lecture.
- 3101. QUANTITATIVE ANALYSIS.** (2 cr, 3100-3101†; for non-chemistry majors; prereq 3100 or †3100; 8 lab hrs per wk)  
Introductory laboratory in quantitative chemical analysis.
- 3301. ELEMENTARY ORGANIC CHEMISTRY I.** (4 cr, †3331; for non-chemistry majors; prereq 1005 or 1032 or equiv; 3 lect, 1 quiz or conf per wk)  
Important classes of organic compounds, both aliphatic and aromatic, together with some heterocyclic compounds.
- 3302. ELEMENTARY ORGANIC CHEMISTRY II.** (4 cr; prereq 3301, 3305 or †3305; 3 lect, 1 quiz or conf per wk; if 3305 is taken concurrently, a passing grade is required for 3305 in order to receive cr for 3302)  
Continuation of 3301.
- 3303. ELEMENTARY ORGANIC CHEMISTRY III.** (4 cr; prereq 3302, 3306 or †3306; 4 lect hrs per wk)  
Basic principles with emphasis on organic reaction mechanisms. Intended to coordinate the knowledge acquired in the preceding 2 quarters.
- 3305. ELEMENTARY ORGANIC CHEMISTRY LABORATORY I.** (2 cr; prereq 3301 or †3301; 1 lab conf, 4 lab hrs per wk)  
Introduces the various techniques utilized in the preparation of typical organic substances.
- 3306. ELEMENTARY ORGANIC CHEMISTRY LABORATORY II.** (2 cr; prereq 3302 or †3302; 1 lab conf, 4 lab hrs per wk)  
Introduces the various techniques utilized in the preparation of typical organic substances.
- 3331. INTRODUCTORY ORGANIC CHEMISTRY I.** (5 cr, †3301; for chemistry and chemical engineering majors; prereq 1133 or 1 yr college chemistry; 5 lect per wk)  
A survey of the important classes of organic compounds; their constitutions, configurations, and conformations; the relationship between molecular structure and chemical reactivity.
- 3332. INTRODUCTORY ORGANIC CHEMISTRY II.** (3 cr, 3332-3335†; prereq 3331; 3 lect per wk)  
A survey of the reactions of organic compounds; nucleophilic substitution and addition; electrophilic substitution and addition; elimination reactions; molecular rearrangements; oxidation and reduction.
- 3333. INTRODUCTORY ORGANIC CHEMISTRY III.** (3 cr; prereq 3332; 3 lect per wk)  
Free radical reactions, electrocyclic reactions, photochemistry, organic synthesis, heterocyclic compounds, synthetic polymers, the chemistry of natural products and life.
- 3335. INTRODUCTORY ORGANIC CHEMISTRY II LAB.** (2 cr, 3332-3335†; prereq 3332 or †3332 [†3332 is recommended] ; two 4-hr labs per wk)  
A laboratory course to accompany 3332.
- 3336. INTRODUCTORY ORGANIC CHEMISTRY III LAB.** (2 cr; prereq 3333 or †3333 [†3333 is recommended] ; two 4-hr labs per wk)  
A laboratory course to accompany 3333.
- 3499. SENIOR THESIS.** (Cr ar; prereq 4th yr. #)  
Written final senior thesis report.
- 3970. DIRECTED STUDY.** (Cr ar; prereq #)  
On- or off-campus learning experiences, individually arranged between a student and chemistry faculty member, in areas not covered by regular courses.
- 3991, 3992, 3993. SPECIAL TOPICS IN CHEMISTRY.** (Cr ar; prereq #)  
Areas of current research. Primarily for third- and fourth-year chemistry majors.
- 5122. ADVANCED ANALYTICAL CHEMISTRY.** (4 cr; prereq 1 yr organic chemistry, course in thermodynamics) Equilibria in aqueous and nonaqueous systems.
- 5126. MODERN ANALYTICAL CHEMISTRY.** (4 cr; primarily for chemical engineering majors; prereq 3332 and 3335; 2 lect and two 3-hr labs per wk)  
Strategies and techniques for solving modern analytical problems. The use of modern instruments in analysis.
- 5127. ANALOG AND DIGITAL INSTRUMENTATION.** (5 cr; prereq Phys 1291, Math 1231 or 1331 or equiv or #; 4 lect and 3 lab hrs per wk)  
Basic principles and applications of electronic circuitry; servo systems, operational amplifiers, feedback control, oscillators, digital gates, and converters for signal processing and control of chemical measurement systems.
- 5128. THE SMALL COMPUTER IN THE CHEMICAL LABORATORY.** (5 cr; prereq 5127 or #; 3 lect and two 4-hr labs per wk)  
Applications of the laboratory computer to the control of chemical instrumentation and acquisition of data. Hardware (interfacing) and software (assembly language programming) aspects of automating the chemical experiment.

## Course Listings

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- 5133. CHEMICAL INSTRUMENTATION AND ANALYSIS.** (5 cr, §5126; prereq 1133, 5534; 3 lect and two 4-hr labs per wk)  
An introduction to the methodology and practices of solving analytical problems. The application of modern instrumental techniques to analysis.
- 5139. CHROMATOGRAPHY AND SEPARATION SCIENCE.** (4 cr; prereq 5133 or equiv or #; 3 lect and one 3-hr lab per wk)  
Fundamental and practical aspects of gas liquid chromatography, modern liquid chromatography, electrophoresis and other techniques used for analysis and separations.
- 5211. ADVANCED CHEMICAL KINETICS.** (4 cr; prereq 5535 or equiv)  
Factors that 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.
- 5212. CHEMICAL DYNAMICS IN SOLUTION.** (4 cr, §8212; prereq undergrad physical chemistry course with a section on kinetics or #)  
Substitution reactions; electron-transfer reactions; electrode reactions; linear free energy relationships; structure of intermediates; ionpairing, solvent effects, ionic strength; diffusion-controlled processes; cage effects.
- 5301. SPECTRAL METHODS FOR ORGANIC QUALITATIVE ANALYSIS.** (4 cr, §8302; prereq 3303 or 3333 or equiv; 3 lect and 1 conf hrs per wk)  
Practical application of nuclear magnetic resonance, mass, and ultraviolet infrared spectral analysis to solution of organic problems.
- 5302. ORGANIC SYNTHESIS.** (4 cr; prereq 3303 or 3333 or equiv; 8 lab 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 3303 or 3333 or equiv; 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. APPLICATIONS OF MOLECULAR ORBITAL THEORY IN ORGANIC CHEMISTRY.** (4 cr; prereq 5536 or Phys 3501 or #)  
Application of quantum mechanics to organic reactions and photochemistry.
- 5342. CHEMISTRY OF NATURAL PRODUCTS.** (3 cr; prereq 3303 or 3333 or equiv; offered 1980-81 and alt yrs)  
Biosynthesis of secondary natural products with emphasis on alkaloids, terpenes, and acetogenins.
- 5343. CHEMISTRY OF NATURAL PRODUCTS (STEROIDS).** (3 cr; prereq 3303 or 3333 or equiv; offered 1979-80 and alt yrs)  
Steroidal hormones, their isolation, proof of structure, synthesis, and action.
- 5344. HETEROCYCLIC COMPOUNDS.** (3 cr; prereq 3303 or 3333 or equiv; offered 1979-80 and alt yrs)  
Typical classes of heterocyclic compounds, their chemical and physical properties and uses, synthesis.
- 5365. ORGANIC QUALITATIVE ANALYSIS.** (4 cr; prereq 3303 or 3333 or equiv; 8 lab and 2 conf hrs per wk)  
Reactions of typical functional groups and introduction to methods of organic structure determination.
- 5520-5521. ELEMENTARY PHYSICAL CHEMISTRY.** (3 cr per qtr; prereq 1 yr college chemistry, Phys 1291 or †Phys 1291 or Phys 1106, Math 3211)  
Brief general survey. 5520: Chemical thermodynamics. 5521: Kinetics, statistical mechanics, molecular structure.
- 5522. PHYSICAL BIOCHEMISTRY OF SOLUTIONS.** (4 cr, §BioC 5522; prereq 2 qtrs physical chemistry ... BioC 5001 or Biol 3021 desirable)  
Physical chemistry of equilibrium and transport phenomena in solution with application to biochemical systems. Macromolecular solutions, phase transitions, cooperative binding, conformational transitions, protein polymerization, micelle formation, sedimentation equilibrium and velocity, translational and rotational diffusion, viscosity.
- 5523. PHYSICAL BIOCHEMISTRY: STRUCTURE AND INTERMOLECULAR FORCES.** (4 cr, §BioC 5523; prereq 2 qtrs physical chemistry ... BioC 5001 or Biol 3021 desirable)  
Methods of structure determination for biological macromolecules. Scattering and diffraction, optical and magnetic resonance spectroscopy. Application to proteins, nucleic acids, and synthetic analogs.
- 5524. BIOPHYSICAL CHEMISTRY: DYNAMICS.** (4 cr, §BioC 5524; prereq 2 qtrs physical chemistry, BioC 5741 ... BioC 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, §5533; intended for beginning grad students not specializing in physical chemistry; prereq Phys 1291 or equiv plus Math 3211 or equiv or #)  
Postulates of quantum mechanics. Introduction to wave functions, solutions of the Schrodinger equation, variation and perturbation theory, modern techniques for calculating bound state wave functions and electronic energies of molecules.
- 5533. QUANTUM CHEMISTRY.** (4 cr, §5531; prereq 1 yr college chemistry, Phys 1291 or fPhys 1291, or 1106 with #, Math 3211)  
Principles of quantum mechanics with applications to atomic and molecular structure and to spectroscopy.
- 5534. CHEMICAL THERMODYNAMICS.** (4 cr; prereq 1 yr college chemistry, Phys 1291 or fPhys 1291, or Phys 1106 with #, Math 3211)  
Principles of thermodynamics with applications to chemical systems.
- 5535. STATISTICAL MECHANICS AND REACTION KINETICS.** (4 cr; prereq 5534)  
(Continuation of 5534) Statistical thermodynamics and the kinetic theory of gases with applications to reaction rate theory. Phenomenological kinetics and experimental methods.
- 5536. QUANTUM CHEMISTRY LABORATORY.** (2 cr; prereq 5533 or f5533)  
Laboratory experiments illustrating principles and methods of quantum mechanics.
- 5538. PHYSICAL CHEMISTRY LABORATORY.** (1 cr; prereq 5535 or f5535)  
Experiments in thermodynamics and reaction kinetics.
- 5571, 5572. MOLECULAR SPECTROSCOPY.** (4 cr per qtr; prereq 5531 or 5533 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 5535 or 5534 or #; offered 1979-80 and alt yrs)  
Molecular weight distribution, statistical mechanics of polymer solutions, network polymers, viscosity, light scattering, viscoelastic behavior.
- 5601. BIOORGANIC CHEMISTRY.** (4 cr; prereq 3303 or 3333 or equiv)  
Chemistry of biologically important functional groups and compounds including amino acids, lipids, carbohydrates, organophosphates. Techniques for radiolabeling and for synthesis of analogs of biologically active molecules.
- 5610. PRINCIPLES OF POLYMER SCIENCE.** (4 cr, §8610, §MatS 5610; prereq physical chemistry or MatS 5011 or #; 3 lect and 3 lab hrs per wk)  
Polymer synthesis and physical chemistry: polymerization kinetics and reactors, molecular weight distribution, network formation, macromolecules in solution and their characterization, the glassy and crystalline state, rubber elasticity, flow and viscoelasticity, environmental degradation.
- 5731. INORGANIC CHEMISTRY I.** (3 cr; prereq 5533; 3 lect hrs per wk)  
Structure, bonding, thermochemistry, acid-base chemistry, physical and chemical properties of inorganic substances. Emphasis on systems where *s* and *p* electrons are important.
- 5732. INORGANIC CHEMISTRY II.** (3 cr; prereq 5731; 3 lect hrs per wk)  
(See 5731) Emphasis on transition metal compounds where *d* electrons are important. Topics of current interest such as boron hydrides, inert gas compounds, organometallic compounds, and biologically important metal compounds.
- 5734. INORGANIC CHEMISTRY LABORATORY I.** (2 cr; prereq 5731 or f5731 or #; 1 lect and 3 lab hrs per wk)  
Laboratory to accompany 5731.
- 5735. INORGANIC CHEMISTRY LABORATORY II.** (2 cr; prereq 5734, 5732 or f5732 or #; 1 lect and 3 lab hrs per wk)  
Laboratory to accompany 5732.
- 5741. ORGANOMETALLIC CHEMISTRY.** (4 cr; prereq 5732 or equiv or #)  
Syntheses, reactions, structures, and other important properties of main group transition metal organometallic compounds; treatment in terms of modern electronic and structural theory. Emphasis on use of these compounds as stoichiometric and homogeneous catalytic reagents in organic and inorganic systems.
- 5742. SURVEY OF THE CHEMISTRY OF THE NONTRANSITION ELEMENTS.** (4 cr; prereq 5732 or equiv or #)  
Reactions and properties of the nontransitional elements, including the rare gases, and their compounds.
- 5743b. SYMMETRY IN CHEMISTRY.** (4 cr; prereq 5732 or equiv or #; offered 1980 and alt yrs)  
Group theory; symmetry classification of inorganic and organic molecules; symmetry point groups; symmetry of wave functions; symmetry aspects of molecular orbital theory.

## Course Listings

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- 5745. SURVEY OF THE CHEMISTRY OF THE TRANSITION METALS.** (4 cr; prereq 5732 or equiv or #)  
Reactions and properties of the transition metals and their compounds. Modern coordination chemistry including magnetic and spectroscopic properties and qualitative ligand field theory.
- 5746. APPLICATIONS OF LIGAND FIELD THEORY.** (4 cr; prereq 5531 or 5533 or equiv or #; offered 1981 and alt yrs)  
Development of ligand field theory at advanced level; applications of the theory to problems of stability, reactivity, magnetic properties, and optical properties of transition metal compounds.
- 5801, 5802, 5803. THE CHEMISTRY OF INDUSTRY.** (4 cr per qtr; prereq chemistry sr or grad student or #)  
The relation between basic chemical theory and chemical technology including programs of economics, ecology, and resources.
- 5991, 5992, 5993. SELECTED TOPICS IN CHEMISTRY.** (Cr ar; prereq sr, Δ)  
Topics of current interest in chemistry. Consult department for details for a particular quarter.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8100. GENERAL SURVEY OF ANALYTICAL CHEMISTRY**
- 8104. OPTICAL METHODS OF ANALYSIS**
- 8129. SURVEY OF MODERN INSTRUMENTAL ANALYSIS**
- 8133. MODERN ELECTROANALYTICAL TECHNIQUES, PRINCIPLES, AND PRACTICES**
- 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**
- 8300. GENERAL SURVEY OF ORGANIC CHEMISTRY**
- 8301. ADVANCED ORGANIC CHEMISTRY I**
- 8302. INTERPRETATION OF ORGANIC SPECTRA**
- 8303. DETERMINATION OF MECHANISMS OF ORGANIC REACTIONS**
- 8304. ADVANCED ORGANIC CHEMISTRY II**
- 8305. ADVANCED ORGANIC CHEMISTRY III**
- 8341. STEREOCHEMISTRY**
- 8342. INTRODUCTION TO RESEARCH**
- 8343. THEORETICAL ORGANIC CHEMISTRY**
- 8344. THEORETICAL ORGANIC CHEMISTRY**
- 8390. ORGANIC CHEMISTRY SEMINAR**
- 8500. GENERAL SURVEY OF PHYSICAL CHEMISTRY**
- 8531-8532-8533. INTRODUCTORY QUANTUM MECHANICS AND SPECTROSCOPY**
- 8534. GROUP THEORY**
- 8535. VIBRATION-ROTATION SPECTRA**
- 8536. ELECTRONIC STRUCTURE AND SPECTROSCOPY**
- 8541-8542-8543. THERMODYNAMICS, STATISTICAL MECHANICS AND KINETICS**
- 8544. COLLISION THEORY**
- 8545. REACTION DYNAMICS**
- 8560. SEMINAR: PHYSICAL CHEMISTRY OF BIOLOGICAL SYSTEMS**
- 8565. SEMINAR: PHYSICAL CHEMISTRY OF POLYMERS**
- 8570. SEMINAR: MOLECULAR SPECTROSCOPY**
- 8571. ADVANCED QUANTUM MECHANICS**
- 8572. INTERACTION OF RADIATION WITH MATTER**

- 8575. SEMINAR: MAGNETOCHEMISTRY
- 8580. SEMINAR: PHOTOCHEMISTRY
- 8581. MAGNETIC RESONANCE
- 8585. SEMINAR: THEORETICAL CHEMISTRY
- 8590. SEMINAR: PHYSICAL CHEMISTRY
- 8601-8602-8603. MOLECULAR THEORY OF TRANSPORT PROCESSES
- 8612. BIOORGANIC REACTION MECHANISMS
- 8650. SEMINAR: SOLID STATE CHEMISTRY AND STRUCTURE
- 8700. GENERAL SURVEY OF INORGANIC CHEMISTRY
- 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. S-N only)  
Fundamentals of civil engineering practice presented by professional engineers and members of the faculty
- 3050. ENGINEERING INTERN WORK ASSIGNMENT. (4 cr [may be taken for cr twice]; S-N only; prereq: regis in intern program)  
Grades based on formal written report by the student covering his or her work during the 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 engineering practice
- 5002. ENGINEERING ECONOMICS. (2 cr, prereq: jr. 2 lect hrs per wk)  
Economic evaluation and engineering decisions, interest and time value of money, economic analysis of alternative designs, depreciation analysis and service life, measurement of costs and benefits for public works, applications to civil engineering projects
- 5097, 5098, 5099. ADVANCED DESIGN, ANALYSIS, RESEARCH, OR TUTORIAL IN CIVIL ENGINEERING. (Cr or [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 Mapping

- 3100. INTRODUCTION TO SURVEYING AND MAPPING. (4 cr; prereq: Math 1211, 3 lect and 3 lab hrs per wk)  
Theory of precision measurements of distance, elevation, angle, and direction. Elements of coordinate systems, datum planes, and maps. Use of aerial photographs for mapping. Fundamentals of geometrics for design, grades, and vertical and horizontal curvature
- 3103. FIELD SURVEYING. (3 cr, prereq: 3100, 3 lab hrs per wk plus 1-week lab)  
Theory and practice of precision measurements of distance, elevation, angle, and direction. Laboratory problems related to the use and application of modern surveying instrumentation
- 5100. LAND SURVEYING. (4 cr; prereq: 3100 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

## Course Listings

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- 5101. GEODESY.** (4 cr; prereq 3100; 3 lect hrs per wk)  
Size and shape of the earth; properties of ellipsoids; reference ellipsoids; Legendre theorem; geodesic and normal sections; direct and inverse geodetic lines; geodetic datums; deflection of the vertical; LaPlace stations. Survey adjustments.
- 5102. SITE AND ROUTE ENGINEERING.** (4 cr; prereq 3100; 3 lect and 3 lab hrs per wk)  
Site and route design fundamentals and problems based on spatial data obtained through photogrammetric mapping. Problems in geometric design; grades, horizontal and vertical curves; fitting of design to topography; earthwork, area and volumes; and drainage. Construction control and layout.
- 5103. LAND PLANNING AND SUBDIVISION DESIGN.** (4 cr; prereq 3100 and 5102; 3 lect and 3 lab hrs per wk)  
Minnesota statutes, county and municipal ordinances governing land use and subdivision. Elements of design. Design of a subdivision.
- 5104. PHOTOGRAMMETRY.** (4 cr; prereq Math 1211; 3 lect and 3 lab hrs per wk)  
Stereoscopy and parallax; geometry of single and overlapping photographs; stereoscopic plotting instruments; flight planning; aerial cameras and calibration; mosaics; terrestrial photogrammetry; principles of photo interpretation; elements of remote sensing; and applications to resource evaluation.
- 5105. SURVEY ADJUSTMENTS.** (4 cr; prereq 3100 and CS 3101 or #; 3 lect hrs per wk)  
Application of statistical theory to adjustment of surveying and photogrammetric measurements. Includes concepts of precision and accuracy, error propagation, observation and condition equations, weighting of observations, solution of systems of equations by method of least squares, and precision of adjusted quantities.

### Transportation

- 3200. INTRODUCTION TO TRANSPORTATION ENGINEERING.** (4 cr; prereq Phys 1271 or equiv)  
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.
- 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; implications 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 SYSTEMS ANALYSIS.** (4 cr; prereq #)  
Techniques of analysis of and planning for transportation services; demand-supply interactions; evaluating transportation alternatives; travel demand forecasting; integrated model systems; citizen participation in decision making; proposal writing.
- 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.

### Geomechanics (Soil Mechanics and Rock Mechanics)

- 3300. ELEMENTS OF SOIL MECHANICS.** (4 cr; prereq AEM 1015; 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.
- 5310. FOUNDATION DESIGN.** (4 cr; prereq 3300)  
Applications of soils engineering to design and construction of shallow foundations, deep foundations, and various types of 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 AND EMBANKMENT DESIGN.** (4 cr; prereq 3300)  
Applications of soils engineering to design and construction of slopes and embankments, considering such aspects as seepage forces, soil strength, and slope geometry.
- 5320. FUNDAMENTALS OF GEOMECHANICS.** (4 cr; prereq 3300; 3 lect and 2 rec hrs per wk)  
Groundwater flow; stress and strain analysis in soil and rock; effective stresses; testing techniques; solutions of simple elasticity problems; stress-strain relations in soil and rock.

- 5321. SLOPES AND FOUNDATIONS I.** (4 cr; prereq 5320; 3 lect and 2 rec hrs per wk)  
One-dimensional consolidation; tests; bearing capacity and settlements; retaining walls and excavations; slope stability in soil and rock; influence of groundwater; pile foundations.
- 5322. SLOPES AND FOUNDATIONS II.** (4 cr; prereq 5321; 3 lect and 2 rec hrs per wk)  
Settlements due to two- and three-dimensional consolidation, pumping and subsidence, negative skin friction of pile foundations. Stress analysis in the failure zone of granular materials; field tests; ground strengthening.

### **Water Resources, Hydraulic Engineering, and Hydrology**

- 3400. FLUID MECHANICS.** (4 cr, §AEM 5200; prereq Math 3221, AEM 1015 or AEM 3016; 3 lect and 3 lab hrs per wk)  
Fluid properties, fluid statics for liquids and gases. Kinematics of fluid flow. Viscous effects. Introduction to incompressible and compressible duct flow, boundary layers, lift and drag, potential flow. Fluid measurements.
- 5401. WATER RESOURCES ENGINEERING.** (4 cr; prereq 3400; 3 lect and 3 lab hrs per wk)  
Introduction to water resources engineering including flow in conduits, pumps, open channels and culverts; introduction to flow measurements, hydraulic structures and systems approach to water resources engineering.
- 5402. HYDRAULIC ANALYSIS WITH COMPUTER APPLICATIONS.** (4 cr; prereq 5401, CSci 3101 or #; 3 lect and 3 lab hrs per wk)  
Computer applications in hydraulic engineering with emphasis on iteration techniques and finite increment methods applied to open channel flow profile analysis; analysis of flow through spillways, bridge waterways, culverts, and similar structures.
- 5405. HYDROLOGY AND HYDROLOGIC DESIGN.** (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, application of hydrology to design of outlet works and flow control structures.
- 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)  
U.S. and world water resources; human water use; economic, environmental, social, and political problems related to water.
- 5435. INTERMEDIATE FLUID MECHANICS WITH APPLICATIONS.** (4 cr; prereq 3400 or #)  
Basic laws and equations of fluid flows; exact and approximate solutions; very viscous flow; flow through porous media, potential and interfacial flows; boundary layer flow; turbulence and transport phenomena.

### **Environmental Engineering**

- 3500. INTRODUCTION TO ENVIRONMENTAL ENGINEERING PROBLEMS AND ANALYSIS.** (4 cr; prereq Chem 1005)  
Environmental problems and an interdisciplinary approach to problem solving. Water pollution, water pollution control technology, air pollution, air pollution control technology, noise, alternative energy resources, solid waste disposal, nuclear energy, radioactive wastes and the overall impact of technology on environmental quality.
- 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 WASTEWATER 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. Volumes and quality of waste streams, treatment and ultimate disposal of domestic and industrial wastewaters, and storm water runoff. Environmental effects, cost, and political aspects of ultimate disposal.
- 5505. WATER QUALITY AND TREATMENT.** (4 cr; prereq 3400, 3500)  
Chemical and physical properties of natural waters, composition of natural waters, introduction to aquatic biology, and ecological considerations of element cycling of natural carbon, nitrogen, phosphorus, oxygen, and anthropogenic chemical species (pesticides, PCBs, heavy metals). Physical and chemical processes of water treatment.

## Course Listings

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- 5510. SOLID WASTE MANAGEMENT.** (4 cr., prereq 3500 or #; 3 lect and 3 lab hrs per wk)  
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 unit costs

### Structural Engineering

- 3600-3601-3602. STRUCTURAL DESIGN FOR ARCHITECTS.** (4 cr per qtr, prereq AEM 3092, 3093, 4 lect and 1 rec hrs per wk)  
Behavior, analysis, design, and construction of structural systems and items in steel, reinforced concrete, timber, masonry, and plastics
- 3605. INTRODUCTION TO STRUCTURAL ANALYSIS.** (4 cr., prereq AEM 1015, not offered 1979-80)  
Principles of structural mechanics, forces and deformations in one-dimensional structural elements; elementary design considerations
- 5600. LINEAR STRUCTURAL SYSTEMS.** (4 cr., prereq 3605 or AEM 3016)  
Analysis of determinate and indeterminate structural systems
- 5601. ANALYSIS OF STRUCTURES.** (4 cr., prereq 5600)  
Analysis of linear structural systems by matrix methods
- 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 and plate girders. Connections
- 5611. DESIGN OF REINFORCED CONCRETE STRUCTURES.** (4 cr., prereq 5600)  
Principles of strength and serviceability in reinforced concrete structural design. Strength analysis, design of beams, joists, one-way slabs for flexure and shear. Anchorage, development, splicing of reinforcement. Stresses at service, loads, deflections, cracking, long-term effects. Introduction to design of columns, continuity, simple footings
- 5612. INTERMEDIATE DESIGN OF METAL STRUCTURES.** (4 cr., prereq 5610)  
Design of complete metal structures, industrial buildings, multistory structural frames, bridges.
- 5613. INTERMEDIATE REINFORCED CONCRETE DESIGN.** (4 cr., prereq 5611)  
Eccentrically loaded columns. Shear friction, design of brackets. Deep beam design. Continuous beams and frames. Combined and continuous footings. Retaining walls. Combination of shear and torsion. Two-way slabs
- 5615. PRESTRESSED CONCRETE.** (4 cr., prereq 5611, 5613 recommended)  
Types and properties of high-strength concretes and steels for prestressed concrete. Design of pretensioned and posttensioned members. Posttensioning systems. Precast, prestressed building systems, floors, roofs, bridges. Continuity in precast, prestressed systems. Design of connections

### Construction Materials

- 3700. INTRODUCTION TO CONSTRUCTION MATERIALS.** (4 cr.; prereq AEM 3016, 3 lect and 3 lab hrs per wk)  
Basic behavior mechanisms of materials and characterization of specific materials such as concretes, metals, woods, and others
- 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

(For course descriptions, see the *Graduate School Bulletin*)

#### 8097-8098-8099. CIVIL ENGINEERING RESEARCH

#### 8200. THEORY OF TRAFFIC FLOW

#### 8201. URBAN TRAFFIC OPERATIONS

#### 8202. FREEWAY TRAFFIC OPERATIONS

- 8210. TRAVEL DEMAND FORECASTING
- 8211. MODELING CONSUMER CHOICES IN TRANSPORTATION
- 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. HYDRO AND THERMAL POWER DEVELOPMENT
- 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
- 8432-8433. HYDRODYNAMICS OF THE BOUNDARY LAYER
- 8435-8436-8437. SPECIAL TOPICS IN HYDRODYNAMIC THEORY
- 8497-8498-8499. ADVANCED HYDRAULIC LABORATORY
- 8500. PHYSICAL AND CHEMICAL PROCESSES FOR WATER AND WASTEWATER TREATMENT—PART I
- 8501. BIOLOGICAL AND CHEMICAL PROCESSES FOR WASTEWATER TREATMENT
- 8502. TECHNIQUES OF WATER AND WASTEWATER ANALYSIS
- 8505, 8506. AQUATIC CHEMISTRY FOR ENVIRONMENTAL ENGINEERS
- 8507. PHYSICAL AND CHEMICAL PROCESSES FOR WATER AND WASTEWATER TREATMENT—PART II
- 8510. INDUSTRIAL WASTEWATER TREATMENT AND DISPOSAL
- 8520. WATER TREATMENT PLANT DESIGN
- 8521. WASTEWATER TREATMENT PLANT DESIGN
- 8550. ANALYSIS AND MODELING OF THE AQUATIC ENVIRONMENT
- 8551. SEMINAR: MODELS OF AQUATIC ENVIRONMENTS
- 8560. SEMINAR: SPECIAL TOPICS IN ENVIRONMENTAL ENGINEERING
- 8605. THE FINITE ELEMENT METHOD IN CIVIL ENGINEERING
- 8606. APPROXIMATE METHODS OF STRUCTURAL ANALYSIS
- 8608. ADVANCED THEORY OF STRUCTURES
- 8609. PRINCIPLES OF STRUCTURAL STABILITY
- 8610. SHELL STRUCTURES
- 8611. PLATE STRUCTURES
- 8612. STRUCTURAL DESIGN BY ULTIMATE LOAD THEORY
- 8616. NONLINEAR STRUCTURAL SYSTEMS
- 8620-8621. STRUCTURAL DYNAMICS I, II
- 8697-8698-8699. SEMINAR: STRUCTURES

## Course Listings

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### Computer Science (CSci)

- 1100. INTRODUCTION TO FORTRAN PROGRAMMING I.** (2 cr; prereq Math 1211 or 1311 or  $\dagger$ Math 1211 or  $\dagger$ 1311 or  $\dagger$ 1611 or #: informal lab)  
Introduction to computer programming using FORTRAN; elementary-intermediate level applications. (See 3101 for comparison.)
- 1101. INTRODUCTION TO FORTRAN PROGRAMMING II.** (2 cr [not open for cr to CSci majors]; prereq 1100 and Math 1211 or 1311 or 1611 or #: informal lab)  
(Continuation of 1100) Extended applications including some numerical methods.
- 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; prereq Math 1211 or 1311 or 1611 or #)  
FORTRAN computer language with extensions; applications; programming techniques. Brings students to advanced-level competence in FORTRAN programming. Integral nonscheduled laboratory.
- 3104. INTRODUCTION TO PROGRAMMING AND PROBLEM SOLVING.** (4 cr; informal lab; required introductory course for all computer science majors)  
Problem-solving techniques, stepwise refinement, modularization. Algorithms, introduction to evaluation criteria, representation of algorithms, flowcharts, metalanguages. The PASCAL language. Elements of programming style, program checking. Design of test data. Documentation. Comparison of PASCAL and FORTRAN.
- 3105. FUNDAMENTALS OF ALGORITHMS AND LANGUAGES I.** (4 cr; prereq 3104 or #: informal lab)  
Informal and formal approaches to algorithms, their properties, analysis, and synthesis (formulation), as well as the correspondence between programming languages and the types of problems to be solved. Numerical algorithms and their implementation in a programming language.
- 3106. FUNDAMENTALS OF ALGORITHMS AND LANGUAGES II.** (4 cr; prereq competence in a higher level language, algorithmic structures at the level of 3105 or #: informal lab)  
Algorithms for nonnumeric data types. Examples from area of language processors, data structures, string processing. Suitable languages; SNOBOL. Textual analysis, recursive processes, their implications for languages and their implementation; excursion into artificial intelligence.
- 3107. INTRODUCTION TO THE STRUCTURE AND PROGRAMMING OF COMPUTER SYSTEMS.** (4 cr, §5101; intended for CSci majors...nonmajors should take 5101; prereq 3104 or equiv or #: informal lab)  
Organization and logical structure of computer systems. Representation of programs and data. Topics: number systems, primitive computer systems, programming in machine language. Extensions to more sophisticated systems, assembly language, sequencing, decision making, arithmetic, logical operations, character manipulation, iteration, subroutines, data description, introduction to assembler software.
- 3400. DISCRETE STRUCTURES OF COMPUTER SCIENCE.** (4 cr; prereq Math 1231 or 1331 or equiv or #)  
Sets and multisets. Proof techniques. Propositional calculus. Combinatorics. Algorithms. Graphs. Trees.
- 5001. THEORY AND APPLICATION OF LINEAR PROGRAMMING ALGORITHMS.** (4 cr; prereq 1101 or 3101 or 3104, Math 3211 or 3142 or #: informal lab)  
Basic solutions to linear systems; inequalities; convex polyhedral sets; linear programming formulation and optimality conditions; theoretical and computational aspects of simplex algorithm; postoptimal analysis, duality, revised simplex and numerically stable methods, upper bounded problems.
- 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; penalty functions; acceleration of convergence; nonconvex problems.
- 5101. STRUCTURE AND PROGRAMMING OF SOFTWARE SYSTEMS I.** (4 cr, §3107; intended for non-CSci majors...majors should take 3107; prereq 1101 or 3101 or 3104 or equiv or #: informal lab)  
The organization and logical structure of computer systems and the representation of programs and data. Covers essentially the same topics as 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)  
Extensions of basic machine architecture; closed subroutines; macros and conditional assembly; input-output; assembly and loading; dynamic resource allocation; introduction to operating systems, job control language, and processes.
- 5104. SYSTEM SIMULATION: LANGUAGES AND TECHNIQUES.** (4 cr; prereq 3107 or 5101, Stat 3091 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. Application to job shops, business, operations research and operating systems.

- 5105. THEORY OF MACHINE ARITHMETIC.** (4 cr; prereq 3107 or 5101 or #; informal lab)  
Residue class arithmetic. Congruences and complement arithmetic. Integral additive and subtractive accumulators. Applications to absolute values and sign arithmetic, scaling and floating point operations.
- 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 I.** (4 cr; prereq 3107 or 5101 or #)  
Introduction. Definition of interactive computer graphics, its goals and its problems. A model system. Data structures for computer graphics, picture structure and transformations. Perspective views of three-dimensional objects. Structures of graphical programming languages. Interaction handling.
- 5117. COMPUTER GRAPHICS II.** (4 cr; prereq 5107 or #)  
Display processor architecture. Data base management and display file handling. Multilevel software systems for enhanced portability and protocol handling in graphical networks. Examples of graphical programming systems. Methodology of curve and surface interpolation and approximation. Programs for three-dimensional display, and curve and surface approximation.
- 5121. INTRODUCTION TO DATA STRUCTURES.** (4 cr; prereq 3106 or #; informal lab)  
Basic concepts of data and their representation. Sequential and linked representations. Arrays, stacks and queues. Chains, circular lists and doubly linked lists. Dynamic storage management. Garbage collection and storage compaction. Generalized lists. Strings. Binary trees and trees. Tree traversal. Graphs. Activity networks.
- 5122. ADVANCED DATA STRUCTURES.** (4 cr; prereq 5121 or #; informal lab)  
Internal and external sorting. Symbol tables. Optimal binary trees. AVL trees. Hashing. B-trees, tries. Files and indexes. ISAM, multilists, inverted files, cellular partitions, differential files.
- 5199. PROBLEMS IN LANGUAGES AND SYSTEMS.** (1-4 cr [may be repeated for cr]; prereq #)  
Special courses or individual study arranged with faculty member.
- 5200. PRINCIPLES OF CONTINUOUS SYSTEM SIMULATION.** (4 cr; prereq 1101, and Math 3221 or 3061 or #; 3 lect and 1 lab hrs per wk)  
Analog computation. Digital simulation of continuous systems. Hybrid computation. Programming systems. Applications of hybrid computation.
- 5201. INTRODUCTION TO COMPUTER ARCHITECTURE.** (4 cr; prereq 3400, 3107 or 5101 or #)  
Gates, elementary digital logic; register transfers, micro operations; processor architecture; organization of microprogram control, arithmetic unit I/O, memory; case studies.
- 5211. DATA COMMUNICATIONS AND COMPUTER NETWORKS.** (4 cr; prereq 5102 or #; informal lab)  
Network classification. Services. Hardware components. Network architecture. Software problems. Research areas.
- 5299. PROBLEMS IN MACHINE DESIGN.** (1-4 cr [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 Math 3211, or # . . . a knowledge of FORTRAN is assumed; informal lab)  
General concept of iteration formulas. Solution of equations. Newton 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. Chebyshev interpolation theory. Gaussian quadrature. Further solution of equations. Multipoint iteration formulas. Starting values. Iterative schemes for linear algebra. Conditioning. Jacobi 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 Lanczos, 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.

## Course Listings

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- 5399. PROBLEMS IN NUMERICAL ANALYSIS.** (1-4 cr (may be repeated for cr); prereq #)  
Special courses or individual study arranged with faculty member.
- 5400. INTRODUCTION TO AUTOMATA THEORY.** (4 cr; prereq 3106 or #)  
Turing machines, computable functions, unsolvability 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 (may be repeated for cr); prereq #; informal lab)  
Special courses or individual study arranged with faculty member.
- 5501. ARTIFICIAL INTELLIGENCE.** (4 cr; prereq 3106 and 5121 or #; informal lab)  
Concept of a "mechanized" intelligence, operational definitions of intelligence. Heuristic search techniques: problem representation, world model representation, solution search. Application to game playing systems. Natural language processing and semantic information systems. Introduction to machine perception and integrated robots. *The future of artificial intelligence.*
- 5502. INTRODUCTION TO OPERATING SYSTEMS.** (4 cr; prereq 5102 or #; informal lab)  
Definition and historical development of operating systems. Classification of 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 COMPILERS I.** (4 cr; prereq 3107 and 5121 or #; informal lab)  
A higher level language (MPL), machine language, loaders, linkage editors; mapping MPL onto machine language, code generation techniques; derivation of an intermediate language and implementation of code generators for intermediate onto machine language. Students will write the back end of an MPL compiler.
- 5504. INTRODUCTION TO COMPILERS II.** (4 cr; prereq 5503 or #; informal lab)  
Lexical scanning together with preprocessing and macro expansion, symbol tables, parsing, intermediate text generation, error detection and correction. Students will design and implement a front end for an MPL compiler.
- 5521. PATTERN RECOGNITION.** (4 cr; prereq Math 3142 or equiv and Stat 3091 or #; informal lab)  
Definition of the problems of pattern recognition, feature selection, measurement techniques, etc. Classification methods: statistical decision theory, nonstatistical techniques. Automatic feature selection. Syntactic pattern recognition. The relationship between mathematical pattern recognition and artificial intelligence. Applications.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8101-8102-8103. COMPUTER OPERATING SYSTEMS: MODELING AND ANALYSIS**
- 8199. SEMINAR: LANGUAGES AND SYSTEMS**
- 8201-8202-8203. MATHEMATICS OF COMPUTERS AND CONTROL DEVICES**
- 8299. SEMINAR: MACHINE DESIGN**
- 8301-8302. COMPUTATION OF SPECIAL FUNCTIONS AND FORMULAS**
- 8303-8304. COMPUTATIONAL METHODS FOR INITIAL AND BOUNDARY VALUE PROBLEMS**
- 8399. SEMINAR: NUMERICAL ANALYSIS**
- 8401-8402. ALGORITHMS—TECHNIQUES AND THEORY**
- 8499. SEMINAR: COMPUTATIONAL THEORY AND LOGIC**
- 8505. OPTIMIZATION IN COMPILERS**
- 8511. ADVANCED CONCEPTS IN ARTIFICIAL INTELLIGENCE**
- 8599. SEMINAR: NONNUMERIC COMPUTATION**
- 8699. SEMINAR: CONTROL SCIENCE**
- 8799. SEMINAR: INFORMATION SCIENCE**

## Electrical Engineering (EE)

- 1000. INTRODUCTION TO ELECTRICAL ENGINEERING.** (1 cr. S-N only. prereq EE lower division)  
An introduction to electrical engineering presented by practicing engineers and members of the faculty
- 1510. ELEMENTS OF ELECTRICAL ENGINEERING.** (5 cr., prereq Math 3211, 3221 Phys 1291 or \*Phys 1291; 5 lect-rec-dem and 3 lab hrs per wk)  
Physical principles underlying the modeling of circuit elements. Two- and three-terminal resistive elements. Kirchhoff laws. Simple resistive circuits. Linearity in circuits. Storage elements. First-order circuits.
- 3000. CIRCUITS.** (4 cr., not for EE majors, prereq Phys 1291, Math 3221 or \*Math 3221, 3 lect and 2 rec-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 3000 or 3010, 3 lect and 2 rec or lab hrs per wk)  
Network theorems; two-ports, active device models, vacuum diodes, semiconductors, amplifiers, non-linear devices; logic circuits
- 3002. ELECTRIC MACHINERY AND POWER DISTRIBUTION.** (5 cr., not for EE majors, prereq Math 3221 or equiv, Phys 1291 or equiv, 4 lect and 2 lab hrs per wk)  
Fundamentals of electric circuit theory, methods of analysis. Transformer operation and polyphase connections. Principles of rotating electric machines. Performance characteristics and application considerations of DC machines, induction machines, and synchronous machines. Introduction to electric power distribution systems
- 3010-3011-3012. CIRCUITS, SIGNALS, AND SYSTEMS I, II, III.** (4 cr per qtr, prereq 1510)  
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
- 3010H-3011H-3012H. HONORS COURSE: CIRCUITS, SIGNALS, AND SYSTEMS I, II, III.** (4 cr per qtr, prereq  $\Delta$ )
- 3050-3051-3052. ELECTRONICS I-II-III.** (4 cr per qtr, prereq 3010-3011-3012 or \*3010-3011-3012)  
Elementary semiconductor physics, physical description of pn junction diodes, bipolar junction transistors, and field effect transistors, large and small signal circuit models for transistors and diodes, applications in elementary, analog and digital circuits, elementary amplifiers at high frequencies, feedback amplifiers, oscillators, differential and operational amplifiers
- 3050H-3051H. HONORS COURSE: ELECTRONICS I-II.** (4 cr per qtr, prereq  $\Delta$ )
- 3100-3101. ELECTROMAGNETIC FIELDS I, II.** (4 cr per qtr, prereq Phys 1291, Math 3231 or \*Math 3231 with #, 3 lect and 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  $\Delta$ )
- 3400-3401-3402. JUNIOR ELECTRICAL ENGINEERING LABORATORY.** (3-3-3 cr per qtr, prereq 3050-3051-5050 or \*3050-3051-5050)  
Experiments in circuits, electronics, and electromagnetic fields
- 3450H-3451H-3452H. ELECTRICAL ENGINEERING HONORS COURSE.** (4-4-3 cr, §§3400-3401-3402, prereq  $\Delta$ )  
Special studies for third-year students in electrical engineering honors program
- 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 in an engineering field, minimum of 360 hours per summer. Requires a technical report
- 3476-3477-3478-3479†. INDUSTRIAL ASSIGNMENT I, II, III, IV.** (2 cr per qtr, prereq regis in intern program)  
Industrial work assignment in engineering intern program. Grade based on student's formal written report covering the quarter's work assignment
- 3950H-3951H-3952H. HONORS PROJECT.** (3 cr per qtr, prereq  $\Delta$ )  
Design project for fourth-year students in electrical engineering honors program
- 3970. DIRECTED STUDIES.** (Cr or [may be repeated for cr], prereq approval of faculty sponsor)  
Undergraduate studies of approved topics, theoretical or experimental in nature
- 5002. DIGITAL SIGNAL PROCESSING.** (4 cr, prereq 3012)  
General concepts of signal processing, discrete-time systems and digital filters
- 5012. ACTIVE FILTER DESIGN.** (4 cr, prereq 3012 or #, 3 lect and 2 lab-rec hrs per wk)  
Description and analysis of linear networks in the frequency domain. Two-port network analysis. Design of active RC filters using operational amplifiers, second-order filters using Sallen-Key circuits, coefficient matching of multiple feedback circuits, state-variable method, etc. Sensitivity and tuning considerations
- 5050H. HONORS COURSE: NONLINEAR ELECTRONIC CIRCUITS.** (4 cr, prereq  $\Delta$ )

## Course Listings

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- 5051. INTRODUCTION TO LOGIC DESIGN.** (4 cr, prereq 3051 or #)  
Integrated logic circuits. Design using logic circuits, memory elements, sequential circuits. Transmission lines and digital signals.
- 5052. LOGIC DESIGN LABORATORY.** (1 cr; prereq #5051; 2 lab hrs per wk)
- 5053. DESIGN OF DIGITAL CIRCUITS.** (4 cr; prereq 5050, 5051 or #; 3 lect and 2 lab hrs per wk)  
Design of digital and nonlinear circuits; circuit structures, device topologies and performance criteria of IC gates. Flip-flops, counters and A/D converters at subsystem level. Theoretical analysis and use of nonlinear behavior of devices.
- 5055. INSTRUMENTATION AND CONTROL ELECTRONICS.** (4 cr; prereq 3012 or #3012, 3052 or #)  
Internal circuitry of modern integrated circuit operational amplifiers; linear and nonlinear applications of operational amplifiers; power amplifiers; semiconductor controlled rectifiers and their applications; linear voltage regulators; switching regulators.
- 5056. ELECTRONIC CIRCUITS LABORATORY.** (1 cr; prereq 3401, #5055; 2 lab hrs per wk)
- 5062. COMMUNICATION CIRCUITS.** (4 cr; prereq 3012, 5055 or #; 3 lect and 2 lab hrs per wk)  
Design and analysis of electronic circuits common to communication systems and instrumentation, incorporating the latest IC technology. Typical circuits include tuned amplifiers, mixers, modulators, and phase-locked loops.
- 5100. ELECTROMAGNETIC FIELDS III.** (4 cr; prereq 3101)  
Plane-wave propagation, transmission lines, antennas, and other topics.
- 5101. ELECTROMAGNETIC FIELDS LABORATORY.** (1 cr; prereq 3401, 5100 or #5100)
- 5112. ELECTROMAGNETIC BOUNDARY VALUE PROBLEMS.** (4 cr, §5110-5111; prereq 5100 or #; 3 lect and 2 lab hrs per wk)  
Review of static field theory with applications. Boundary-value problems. Quasi-statics. Reflection and refraction of plane waves. Properties of guided waves. Rectangular and circular wave guides. Resonant cavities.
- 5113. PROPAGATION OF ELECTROMAGNETIC FIELDS.** (4 cr, §5110-5111; prereq 5100 or #; 3 lect and 2 lab hrs per wk)  
Review of transients on transmission lines. Pulses on lossy transmission lines. Coupled transmission lines. Superconducting transmission lines. Microwave networks and S-parameter design. Radiation and antenna arrays. Wave propagation in anisotropic media. Microwave electronics.
- 5120. ACOUSTICS FOR ARCHITECTS AND PLANNERS.** (3 cr; not for EE majors; prereq Math 1231, Phys 1122 or 1052 or #, some background in statistical methods desirable)  
Studies of sound both indoors and out-of-doors with special reference to noise and its abatement. Building and community noise sources, their properties and response measures. Design procedures for noise control in building technology and urban planning.
- 5150. ELECTRICAL ENGINEERING MATERIALS.** (4 cr; prereq 3101, Phys 3501 or #)  
Electric, magnetic, and dielectric properties of materials as related to devices used in electrical engineering.
- 5160-5161. PHYSICAL ELECTRONICS.** (4 cr per qtr; prereq 3101 or #; 3 lect and 2 lab hrs per wk)  
Physical principles underlying devices used in electrical engineering; elementary quantum and statistical mechanics, photoemission, electron diffraction and emission. Charged-particle dynamics and diffraction. Semiconductor properties. Special topics of current interest.
- 5202. ANALOG COMMUNICATION.** (4 cr; prereq 3012, Stat 3091 or #; 3 lect and 2 lab hrs per wk)  
Selected topics in analog communication systems: Amplitude and frequency modulation. Spectral analysis and effect of noise in modulation systems. Detection.
- 5203. DATA COMMUNICATION.** (4 cr; prereq 3012, Stat 3091 or #; 3 lect and 2 lab hrs per wk)  
Selected topics in pulse and digital communication systems: pulse modulation systems, pulse-code modulation. Data transmission systems including phase-shift keying and frequency-shift keying. Effect of noise. Coding.
- 5252. DISCRETE CONTROL SYSTEMS.** (4 cr; prereq 5002 or #5002 or #; 3 lect and 2 lab hrs per wk)  
Time-domain representation and analysis of discrete systems; Z-transform. Design of discrete controllers. Computer control systems. Computer simulation.
- 5253. LINEAR CONTROL SYSTEMS.** (4 cr; prereq 3012 or #; 3 lect and 2 lab hrs per wk)  
Modeling, characteristics, and performance of feedback control systems. Stability, root-locus and frequency-response methods. Compensator design.
- 5300. ELECTROMECHANICS.** (4 cr; prereq 3101, 3011 or #)  
Lumped parameter models of magnetic and electric field systems; energy methods, quasi-static electromagnetics and circuit characterization. Induction and synchronous rotating machines; incremental motion transducers. Associated laboratory using a generalized rotating machine to illustrate the basic characteristics of typical electromagnetic energy conversion machines.

- 5310. ELECTRIC POWER SYSTEMS.** (4 cr; prereq 5300 or #; 3 lect and 2 lab hrs per wk)  
Introduction to power system engineering. Modeling of power system components: transformers, synchronous generators, transmission lines, cables, and circuit breakers. Describing equations for power networks. Solution techniques for load-flow and fault studies. Power system relaying.
- 5322. ELECTROMECHANICAL PROCESSES AND DEVICES.** (4 cr; prereq 5300 or #; 3 lect and 2 lab hrs per wk)  
Principles of electromechanical energy conversion. Modeling of rotating machines. Computer-aided steady-state analysis of DC and AC machines. Special purpose devices: Single-phase machines, linear machines, stepper motors. Solid-state motor control.
- 5332. ENERGY CONVERSION SYSTEMS.** (4 cr; prereq sr standing in IT or #)  
Energy conversion problem. Principles of energy conversion; laws of thermodynamics. Thermoelectric generators, thermionic converters, magnetohydrodynamic systems. Solar energy conversion, geothermal systems, fuel cells. Nuclear plants, fusion power.
- 5352. DESIGN OF DIGITAL SYSTEMS.** (4 cr, §5851, §5852, §5351; prereq 5051, 5052 or #; 3 lect and 2 lab hrs per wk)  
Structure of a digital system. Systematic design procedure. Clock and sequencer design and control. The digital computer.
- 5450. SPECIAL INVESTIGATIONS.** (Cr or [may be repeated for cr] ; prereq Δ)  
Studies of approved topics, theoretical or experimental in nature.

## FOR GRADUATE STUDENTS AND QUALIFIED SENIORS

- 5500-5501-5502. SYNTHESIS OF ACTIVE AND PASSIVE NETWORKS.** (3 cr per qtr; prereq 5012 or grad standing or #)  
5500: Two-port parameters, indefinite admittance matrix, and their applications. Theory and testing of positive real functions. Synthesis of two-element-kind networks and RLC driving-point functions. Properties of two-port network functions. 5501: Relationship between parts of network functions. Butterworth, Thomson, Chebyshev, and elliptic approximations; frequency transformation and distortion. Synthesis of LC, RC, and RLC two-ports. 5502: Properties and frequency compensation of operational amplifiers and gyrators. Synthesis of active RC filters by several methods. Sensitivity analysis and comparison of active filters.
- 5511-5512. DIGITAL FILTERS AND SIGNAL PROCESSING.** (3 cr per qtr; prereq 5002 or #)  
5511: Theory of discrete-time systems, Z-transform, sampling and interpolation. Discrete-Fourier transform. Several methods of designing finite-impulse-response (FIR) and infinite-impulse-response filters. 5512: Quantization effects. Theory of two-dimensional digital filters and image processing. Fast-Fourier transform and applications of digital signal processing. Adaptive and homomorphic filtering.
- 5550-5551-5552. SWITCHING AND DIGITAL CIRCUITS.** (3 cr per qtr; prereq 5050 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 #)  
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 hazard. Experiments in neural and muscle stimulation, EKG and EMG recording, neuron simulation, filtering and low-noise amplifiers.
- 5610. ENGINEERING APPLICATIONS OF COHERENT LIGHT.** (3 cr; prereq 5100 or Phys 3011 or #)  
Sources of coherent light. Coherent light beams with treatment of coherence, diffraction, Gaussian beams, and phase locking. Properties and uses of crystalline materials as modulators. Topics include holography, integrated optics, and laser-induced fusion.
- 5620. ENVIRONMENTAL ACOUSTICS AND NOISE.** (4 cr; prereq sr standing in IT or #)  
Energy and Fourier methods with other quantitative aspects of noise including spectra; spectral level, the decibel and its utility; methods of noise source modeling; acoustic propagation effects, attenuation. Noise impact prediction methods for transportation systems and building technology. Methods of noise abatement, influence of criteria and standards.
- 5630. CONTEMPORARY OPTICS.** (4 cr; prereq 5100 or Phys 3012 or #)  
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.
- 5650. DYNAMICAL METHODS IN ELECTRICAL ENGINEERING.** (3 cr; prereq #)  
Lagrange and Hamilton formulations of dynamics, with applications to electromagnetic systems. Lagrange equations; dissipative forces, normal coordinates and small oscillations; Hamilton equations; variational principles for discrete and continuous systems.

## Course Listings

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- 5651. THERMODYNAMIC METHODS IN ELECTRICAL ENGINEERING.** (3 cr; prereq #)  
Basic thermodynamic concepts and laws with applications 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 applications to materials and problems of electrical engineering. Statistical ensembles, phase space, Liouville theorem, the canonical ensemble, the partition function. Classical and quantum statistics. Relation between statistical mechanics and thermodynamics. Classical and quantum calculations of susceptibilities.
- 5660-5661-5662. SEMICONDUCTOR PROPERTIES AND DEVICES.** (3 cr per qtr; prereq 3101 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 principles.
- 5666-5667-5668. MAGNETIC PROPERTIES OF MATERIALS AND APPLICATIONS.** (3 cr per qtr; prereq #)  
5666: Magnetic measurement techniques, physical principles of magnetism, and properties of magnetic materials with applications. 5667: Physical principles of crystalline and induced magnetic anisotropy, magnetostriction, magnetic domains and the magnetization process, fine particles and thin films and magnetization dynamics. 5668: Properties of soft and hard magnetic materials with applications such as thin film memories, permanent magnets, magnetic recording, and magneto-optics.
- 5670. BASIC MICROELECTRONICS.** (4 cr; prereq #)  
Experimental and theoretical studies of the basic physical processes used in microelectronic device fabrication. Transistor and integrated circuit layout, fabrication, and evaluation.
- 5700. INFORMATION THEORY AND CODING.** (3 cr; prereq Stat 3091 or #)  
Discrete information sources and channels, source encoding, the binary channel and Shannon theorem. Block codes for the binary channel.
- 5702. STOCHASTIC PROCESSES AND OPTIMUM FILTERING.** (3 cr; prereq Stat 3091, grad standing or #)  
Stochastic processes, linear system response to stochastic inputs. Gaussian process, Markov process. Linear filtering, maximum likelihood estimate, stochastic control.
- 5703. MODULATION SYSTEMS.** (3 cr; prereq 5702)  
Mathematical models and effects of noise on modulation systems such as AM, FM, PCM. Data-communication systems including frequency- and phase-shift keying; bit-error probabilities.
- 5750. TOPICS IN SYSTEM ANALYSIS.** (3 cr; prereq grad standing or #)  
Linear system models, controllability, observability, stability. Structure of linear systems. Minimization on inner product spaces.
- 5751. OPTIMIZATION TECHNIQUES.** (3 cr; prereq grad standing or #)  
Finite dimensional optimization, infinite dimensional optimization. Controller synthesis for the linear, quadratic problem.
- 5752. NONLINEAR SYSTEM DESIGN.** (3 cr; prereq grad standing or #)  
Characteristics of nonlinear systems, analysis of singular points, limit cycles, describing functions, Lyapunov and Popov stability, computer simulation.
- 5760. BIOLOGICAL SYSTEM MODELING AND ANALYSIS.** (4 cr; prereq #)  
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.
- 5802. ELECTRIC POWER SYSTEM ANALYSIS.** (3 cr; prereq #)  
Formulation of describing equations and advanced computer methods of analysis of large-scale electric power systems. Applications to the load-flow problem, faulted-system calculations, stability studies, and economic environmental dispatch.
- 5805. ELECTRIC POWER SYSTEM ENGINEERING.** (3 cr; prereq #)  
Control of large power systems. Power system overvoltages and transients caused by faults, switching surges, and lightning. AC and DC electric power transmission and distribution, overhead and underground. Environmental impact of electrical energy systems. Current research topics.
- 5808. DIRECT-CURRENT POWER CONVERSION AND TRANSMISSION.** (3 cr; prereq #)  
General aspects of DC power transmission and comparison with AC transmission. Theory of operation and control of solid state AC/DC power converters. Transients due to long DC transmission lines. System protection and harmonic filtering. Environmental impact. Current research topics.
- 5820. ELECTROMECHANICAL SYSTEM DYNAMICS.** (3 cr; prereq #)  
Electromechanical transducers and rotating machines and their dynamic performance in systems. State models of machines. Computer-aided analysis of typical transient operations. Small-signal analysis. Transient stability of power systems. Electromechanical components in control systems. Engineering applications.

- 5851. APPLIED SWITCHING THEORY.** (3 cr; prereq 5051 or #)  
Boolean algebra. Synthesis with practical logic circuits. Combinational logic hazards. Sequential circuit theory and practical design techniques.
- 5852-5853. DIGITAL COMPUTER SYSTEMS.** (3 cr per qtr; prereq 5851, CSci 3101 or CSci 1101 or #)  
Digital computer organization; register-level simulation; control unit design; microprogramming; memory organization. Computer input/output techniques; arithmetic unit design; high-speed arithmetic; features of larger computers.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8000. ADVANCED TOPICS IN NETWORK THEORY**
- 8051-8052-8053. LARGE-SCALE INTEGRATED CIRCUITS**
- 8060. BIPOLAR TRANSISTOR THEORY**
- 8090. ELECTRONICS SEMINAR**
- 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**
- 8192. SEMINAR: MAGNETICS**
- 8204. SIGNAL DETECTION AND ESTIMATION THEORY WITH APPLICATIONS**
- 8211. CODING THEORY**
- 8220. 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**
- 8256. TOPICS IN STOCHASTIC FILTERING AND CONTROL**
- 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**
- 8352. ADVANCED SWITCHING THEORY**
- 8353. SEQUENTIAL CIRCUIT THEORY**
- 8355. COMPUTER ARCHITECTURE I**

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- 8356. COMPUTER ARCHITECTURE II
- 8390. COMPUTER SYSTEMS SEMINAR
- 8450. SPECIAL INVESTIGATIONS
- 8451. ADVANCED TOPICS IN ELECTRICAL ENGINEERING

## Engineering Graphics (EG)

- 1001. **THE SLIDE RULE.** (1 cr [no cr for IT students] ; previous courses in higher algebra and trigonometry recommended; 1 lect hr per wk)  
Computation practice and theory. Design of special scales.
- 1025. **ENGINEERING GRAPHICS.** (4 cr; Math 1211 or equiv recommended; 3 lect and 1 rec hrs per wk, open lab hrs)  
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. **GRAPHIC ENGINEERING COMMUNICATION.** (2 cr, §1025; 2 lect hrs per wk, open lab hrs)  
Engineering representation in pictorial and multiview; sketching techniques and size description.
- 1027. **GRAPHIC ANALYSIS.** (2 cr, §1025; prereq 1026 or high school course in graphics; 2 lect hrs per wk, open lab hrs)  
Analysis of systems of projection; the coordinate system; comparative solutions of three-dimensional problems using graphical, algebraic, and computer methods. Graphic representation of data, empirical analysis. Computer-graphic solutions.
- 3028. **GRAPHICAL COMPUTATION AND EMPIRICAL ANALYSIS.** (4 cr; Math 1221 and Phys 1271 or equiv recommended; 3 lect hrs per wk, open lab hrs)  
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; 1025 or equiv recommended; 3 lect hrs per wk, open lab hrs)  
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; 1025 or equiv recommended; hrs ar)  
A synthesis and extension of the procedures of graphical mathematics, nomography, and/or descriptive geometry as applied to solutions of complex problems within the 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 field 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 FIELDWORK.** (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 ore bodies. 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 or grad student)  
Exploration programming in relation to theories of ore genesis. Analyses of effects of contract and lease requirements on decisions and planning. Statistical analyses in ore estimates. Case histories. Special problems.

- 5216. GEO-ENGINEERING I.** (3 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.
- 5218. TUNNELING TECHNOLOGY.** (3 cr; prereq 5216 or CE 3300 or #: 3 lect hrs per wk)  
Site investigation; excavation and material handling systems; groundwater control; ventilation systems; introduction to selection of support and lining systems; portals; introduction to cost estimates; construction in both soil and rock by either cut and cover or mining. Case histories.
- 5260-5262. GEO-ENGINEERING ANALYSIS.** (4 cr; prereq sr or #: 8 lab hrs per wk)  
Comprehensive analysis of a geological engineering or rock mechanics problem chosen by the student and staff. Involves the integration of concepts of rock and soil mechanics, geology and geophysics, mineral engineering and economics. Preparation of a professional report.
- 5320. FUNDAMENTALS OF GEOMECHANICS.** (4 cr; prereq 3300; 3 lect and 2 rec hrs per wk)  
Groundwater flow; stress and strain analysis in soil and rock; effective stresses; testing techniques; solutions of simple elasticity problems; stress-strain relations in soil and rock.
- 5321. SLOPES AND FOUNDATIONS I.** (4 cr; prereq 5320; 3 lect and 2 rec hrs per wk)  
One-dimensional consolidation; tests; bearing capacity and settlements; retaining walls and excavations; slope stability in soil and rock; influence of groundwater; pile foundations.
- 5322. SLOPES AND FOUNDATIONS II.** (4 cr; prereq 5321; 3 lect and 2 rec hrs per wk)  
Settlements due to two- and three-dimensional consolidation, pumping and subsidence, negative skin friction of pile foundations; stress analysis in the failure zone of granular materials; field tests; ground strengthening.
- 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.
- 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 of linear equations, curve fitting, regression analysis and iterative methods in 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

(For course descriptions, see the *Graduate School Bulletin*)

- 8336. ANALYTICAL METHODS IN ROCK MECHANICS**
- 8350-8352. ADVANCED ROCK MECHANICS I, II**

## Geology and Geophysics (Geo)

- 1001f,w,s. PHYSICAL GEOLOGY.** (5 cr; 4 lect hrs, one 2-hr lab per wk) Staff  
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) Staff  
A special course for nonscience majors, taught on an informal basis by senior faculty members. An introduction to the world of geology. Lectures, field trips, and lab problems.
- 1002w,s. HISTORICAL GEOLOGY.** (4 cr; prereq 1001; 3 lect hrs and one 2-hr lab per wk) Sloan  
Evolution of earth from its origin to present; the succession of physical and biological events of past 600 million years.
- 1005w. GEOLOGIC PERSPECTIVES ON ENERGY.** (3 cr; 3 lect hrs per wk)  
Introduction to the geologic aspects of energy resources, conventional and nonconventional. History of energy use, distribution and amounts of known and potential reserves, environmental aspects and implications of U.S. consumption patterns.
- 1007s. ENVIRONMENTAL GEOLOGY.** (4 cr, §1008; prereq 1001) Wright  
Geological application in resource management, land use planning, technology, and conservation. Geological evolution of the biosphere and the impact of human activities on land, sea, and air resources. Geological hazards. The Twin Cities metropolitan area as a geological environment. Lectures, labs, and field trips.

## Course Listings

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- 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. 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 of 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-cell organisms, planets, animals, and ecosystems. Problems of extraterrestrial life.
- 1111f. INTRODUCTORY PHYSICAL GEOLOGY.** (5 cr; prereq high school or college chemistry or #; 3 lect hrs, 1 rec hr, and two 2-hr labs per wk) Shaw  
For prospective majors and others desiring a more intensive lecture and laboratory sequence than 1001.
- 1601w. OCEANOGRAPHY.** (4 cr; 3 lect and 1 lab hrs per wk)  
How various processes in the ocean interact; analogies between the oceans and Lake Superior and smaller lakes in Minnesota. Topics include marine biology, waves, tides, chemical oceanography, marine geology and human interaction with the sea. Lab work includes study of live marine invertebrates and manipulation of oceanographic data.
- 3099f,w,s. PROBLEMS IN GEOLOGY AND GEOPHYSICS.** (1-6 cr; prereq # and  $\Delta$ )  
Individual research or problem selected on the basis of individual interests and background.
- 3101f. SURFICIAL GEOLOGIC PROCESSES.** (5 cr; prereq 3102 and 3401 or #)  
Geological processes acting at the surface of the earth.
- 3102s. PETROLOGY.** (5 cr; prereq 3401 or #) Stout  
Introduction to the lithologic character and genesis of igneous, metamorphic, and sedimentary 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.
- 3112w. 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 a more intensive course than 1002.
- 3401w. INTRODUCTORY MINERALOGY.** (5 cr; prereq 1001 or 1111 or #, 1 term college chemistry, Math 1221; 3 lect and 6 lab hrs per wk) Zoltai, Stout  
Crystallography, crystal chemistry, and crystal physics. Physical and chemical properties, crystal structures, and chemical equilibria of the major mineral groups. Laboratory includes crystallographic, polarizing microscope, X-ray powder diffraction exercises, and hand specimen mineral identification.
- 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 grad students in education; prereq 1001 or #, 1 term college chemistry, Math 1221; 3 lect and 6 lab hrs per wk) Zoltai, Stout  
See 3401.
- 5051su. PHYSICAL GEOLOGY FOR TEACHERS.** (4 cr, §1001, §1111; prereq education degree, 1 term college chemistry or physics)  
Introduction to scientific methods and nature of the earth, main features of physical world and processes that have formed them.
- 5052su. HISTORICAL GEOLOGY FOR TEACHERS.** (4 cr, §1002, §3112; prereq education degree, 1001 or 1111 or 5051 or #)  
Introduction to origin of the earth, physical evolution of its crust through geological time, and biological changes that occurred during its history. Laboratory, fieldwork, and seminar.
- 5100. ADVANCED GENERAL GEOLOGY.** (2 cr [may be repeated for cr] ; S-N only; prereq 1001 or 1111) Staff  
Seminar course on geology of an area, followed by field trip to the location being studied. Region studied will vary from year to year.
- 5102.\* PHYSICAL STRATIGRAPHY.** (4 cr; prereq 3103) Swain  
Lectures, readings, discussions of modern literature, and laboratory 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 or #) Plannkuch  
Human impact on the geological environment and the effect of geology geologic processes on human life from the point of view of ecosystems and biogeochemical cycles. Geologic limits to resources and carrying capacity of the earth. Land use planning, environmental impact assessment, ecogeologic world models.
- 5110su. FIELD GEOLOGY.** (9 cr. open only to geology, geophysics, and geo-engineering majors. prereq 3103 and #)  
Measurement of stratigraphic sections. Fossils and igneous, sedimentary, and metamorphic rocks. Geological surveying on aerial photographs and topographic maps. Preparation of geologic maps and cross sections. 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 study of morphology, classification, and ecology of selected groups of invertebrate fossils.
- 5154w. VERTEBRATE PALEONTOLOGY I.** (5 cr. prereq 5151 or EBB 5114) Sloan  
Morphology, evolution, and stratigraphic distribution of fossil fish, amphibians, reptiles, and birds.
- 5155s. VERTEBRATE PALEONTOLOGY II.** (5 cr; prereq 5154 or EBB 5114) Sloan  
Morphology, evolution, and stratigraphic distribution of fossil mammals.
- 5156. ZOOARCHAEOLOGY.** (5 cr; primarily for paleontology, anthropology or classics students; prereq 5155 or #, 3 lect and 2 lab hrs per wk. offered 1979 and alt yrs)  
Identification and interpretation of animal remains in an archaeological context.
- 5251s.\* GEOMORPHOLOGY.** (4 cr [5 cr with term project] ; prereq 1001, Math 1111 or #) Hooke  
The origin, development, and continuing evolution of landforms in various environments. Environmental implications are emphasized. Weathering, slope and shore processes, fluvial erosion and deposition, wind action, tectonics, and impact phenomena.
- 5253. SEDIMENT TRANSPORT MECHANISMS.** (3 cr; prereq 5251 or 5652 or CE 5410)  
Properties of sediment, water bed interaction, types of transport (bed load, suspended load), suspension of sediment, sediment transport theories, consequences of sediment movement in alluvial channels.
- 5255w.\* GLACIOLOGY.** (3 cr [4 cr with term project] ; prereq Math 3221 or equiv or #) Hooke  
Theories of glacier flow. Internal structures and heat flow in glaciers and ice sheets. Reading assignments and problems.
- 5261f.\* GLACIAL GEOLOGY.** (4 cr [5 cr with term paper or lab] ; 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. AQUEOUS GEOCHEMISTRY.** (3 cr; prereq Chem 5501 or Chem 5520)  
Chemical processes in the oceans, mineral equilibria, and exchange with the atmosphere. Redox processes and controls of the chemistry of natural waters.
- 5302s. NUCLEAR GEOLOGY.** (4 cr; prereq #) Alexander  
The theory and practice of radioactive dating. Emphasis is on K/Ar, Rb/Sr and U, Th/Pb method as applied to geologic problems. Detailed study of the use of isotopic tracer techniques in crust-mantle evolution, igneous processes and the early history of the earth.
- 5303. GENERAL GEOCHEMISTRY.** (3 cr; prereq 1 qtr chemistry, #) Seyfried, Alexander  
Basic principles of geochemistry; stresses distribution and mobilization of elements in the earth's crust, stable isotope geochemistry, and geochemical reactions involved in the formation of igneous, metamorphic, and sedimentary rocks.
- 5351f.\* METAL SULFIDE DEPOSITS.** (5 cr with lab, 3 cr without lab; 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.
- 5352. GEOLOGY OF FERROUS METAL AND NONMETALLIC DEPOSITS.** (4 cr; prereq 3401, 3103 or #)  
Environmental setting, mineralogy, and genesis of ferrous metal ore deposits and nonmetallic deposits.
- 5361f. GEOLOGY OF FUEL DEPOSITS.** (3 cr; prereq 3101, 3103 or 5002 or #) Swain  
Origin and distribution of petroleum and coal deposits; source materials, reservoir rocks and structures, stratigraphic distribution of important deposits.
- 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.

## Course Listings

- 5404. MINERAL SYSTEMS I.** (4 cr, §3401, §5004; prereq 1 qtr chemistry) Zoltai  
Crystallography; basic and compound symmetry operations, point and space groups, crystal forms and coordinate systems. Systematics of basic and derivative close-packed and coordination polyhedral structures of rock forming and ore minerals. Demonstrations of crystallographic and crystal structural concepts.
- 5405. MINERAL SYSTEMS II.** (4 cr; prereq 3401 or 5404, 1 qtr physics) Shaw  
Review of optical mineralogy. Bonding and relative size of atoms and ions. Chemical substitutions. Crystal growth and imperfections. X-ray powder diffraction. Thermal, electric, elastic, and magnetic properties of minerals. Absorption phenomena. Laboratory: optical mineralogy and crystal physics exercises.
- 5442. ADVANCED MINERALOGY.** (4 cr; prereq 3401)  
Systematic mineralogy of the rock-forming minerals; their structural, geochemical, petrological, and physical characteristics and relationships. Individual laboratory investigations.
- 5452a.\* IGNEOUS AND METAMORPHIC PETROLOGY.** (4 cr; prereq 3102, Chem 5520 or 5521, Math 3211 or #)  
Stout  
Theoretically oriented treatment of the basic thermodynamic tools for interpreting the mineralogy of igneous and metamorphic rocks. Integration of the data of experimental petrology, field geology, and petrography with a theoretical approach to better understand chemical processes in the earth's crust and mantle. 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.
- 5513a.\* 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.
- 5523a. PRINCIPLES OF DIRECT-CURRENT ELECTRICAL EXPLORATION.** (2 cr, §5513; primarily for civil engineering and geo-engineering students; prereq Phys 1291) Mooney  
Resistivity and other direct-current methods.
- 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 sea floor spreading.
- 5601f. LIMNOLOGY.** (4 cr, §EBB 5601; prereq Chem 1005 or equiv) Shapiro  
Description and analysis of events occurring in lakes, reservoirs, and ponds, from their origins through their physics, chemistry, and biology. Emphasis on interrelationships of these parameters and on effects of civilization on lakes.
- 5602f. CASE STUDIES IN LIMNOLOGY.** (3 cr; prereq 5601 or EBB 5601, and #; offered 1980 and alt yrs) Shapiro
- 5611a. GROUNDWATER GEOLOGY.** (4 cr; prereq 1001 or 1111, Math 1231, 1 qtr physics and chemistry or #)  
Plannkuch  
Origin, occurrence, and movement of groundwater viewed in the context of the hydrologic cycle. Characteristics of aquifer systems. Exploratory investigations. Hydrogeologic units and boundaries of regional systems. Analysis of surface water groundwater interaction, recharge. Quality and chemistry of groundwater supplies.
- 5642f. MARINE GEOLOGY.** (4 cr; prereq geology core course sequence or #)  
Physiography and structure of ocean basins and continental margins; their development as suggested by concepts of global tectonics. Emphasis on geologic processes in the marine environment. Review of marine geological and geophysical techniques.
- 5652a.\* SEDIMENTOLOGY.** (5 cr; prereq 3101, 3103 and 5642 or #) Johnson  
Sedimentary processes and products with emphasis on sedimentary rocks.

**FOR GRADUATE STUDENTS ONLY  
OR FOR SENIORS WITH SPECIAL PERMISSION**

(For course descriptions, see the *Graduate School Bulletin*)

***General Geology***

- 8098. SEMINAR: CURRENT TOPICS IN GEOLOGY AND GEOPHYSICS
- 8099. RESEARCH IN GEOLOGY AND GEOPHYSICS
- 8103. BIOSTRATIGRAPHY
- 8152. ADVANCED INVERTEBRATE PALEONTOLOGY
- 8156. MICROPALEONTOLOGY
- 8201. GEOTECTONICS
- 8202. ADVANCED STRUCTURAL GEOLOGY
- 8262. PLEISTOCENE GEOLOGY
- 8657. MARINE SEDIMENTS

***Mineralogy and Petrology***

- 8351. ADVANCED MINERAL DEPOSITS I
- 8353. GEOCHEMISTRY OF HYDROTHERMAL SYSTEMS
- 8361. MINERAL FUEL DEPOSITS
- 8402. X-RAY MINERALOGY
- 8404. X-RAY CRYSTALLOGRAPHY
- 8419. SEMINAR: CLAY MINERALOGY
- 8453. PHASE EQUILIBRIA IN MINERAL SYSTEMS
- 8454. IGNEOUS PETROLOGY
- 8455. METAMORPHIC PETROLOGY

***Hydrogeology***

- 8311. ORGANIC GEOCHEMISTRY
- 8602. ADVANCED LIMNOLOGY
- 8603. METHODS FOR ANALYSIS OF NATURAL WATERS
- 8611. TRANSPORT PHENOMENA IN NATURAL POROUS MEDIA
- 8612. ANALYTICAL GEOHYDROLOGY
- 8651. SEDIMENTARY GEOCHEMISTRY

***Geophysics***

- 8521. LINEAR DATA PROCESSING WITH GEOPHYSICAL APPLICATIONS
- 8531-8532. THEORY OF ELASTIC WAVE PROPAGATION I, II
- 8542. PRINCIPLES OF ROCK MAGNETISM
- 8551. EQUATION OF STATE AND CONSTITUTION OF THE EARTH'S INTERIOR
- 8562. STUDIES OF THE CRUST AND UPPER MANTLE

**History of Science and Technology (HSci)**

Courses may be taken to support existing majors as well as to broaden knowledge of the nature and development of science and technology. All courses satisfy group C distribution requirements.

## Course Listings

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- 1711, 1712, 1713. TECHNOLOGY AND WESTERN CIVILIZATION.** (4 cr per qtr, \$3711, \$3712, \$3713) Layton  
History and sociocultural relations of Western technology. 1711: The relations of technology to culture from the Bronze Age to the Middle Ages. 1712: Technology and science in the Renaissance; technology and the scientific revolution; emergence of industrialism. 1713: Diffusion of the industrial revolution; technological development and its impact on industry, government, and society.
- 1811, 1812, 1813. INTRODUCTION TO HISTORY OF SCIENCE.** (4 cr per qtr, \$3811, \$3812, \$3813) Shapiro  
1811: Babylonian and Egyptian science; Greek natural philosophy, mathematics, astronomy, and biology; the Aristotelian world; decline and transmission of Greek science. 1812: Medieval background; the "experimental philosophy": dissecting and describing nature; anatomy, circulation, and respiration; Copernican revolution; physical world of Kepler, Galileo, Descartes, and Newton; science and the popular imagination. 1813: 19th and 20th centuries; Newtonian triumph, romantic reaction, and modern revolution; the aether, electrical and optical, to Einstein; history of the earth; evolution before and after Darwin; nuclear physics and nuclear weapons.
- 3201, 3202, 3203. HISTORY OF BIOLOGY.** (4 cr per qtr, \$5201, \$5202, \$5203) Kottler  
3201: Antiquity to 1700. Biology, medicine, and natural history in antiquity: Hippocrates, Aristotle, Galen. Revival of biology in Renaissance and 17th century: Vesalius and anatomy, Harvey and circulation. 3202: Physiology and cell theory since 1700. Conceptual development of the various branches of modern biology: physiology, chemistry, and the experimental method; embryology, descriptive and experimental; cytology and microscopy. 3203: Evolution and genetics since 1700. Darwin and evolution, Mendel and genetics.
- 3711, 3712, 3713. TECHNOLOGY AND WESTERN CIVILIZATION.** (4 cr per qtr, \$1711, \$1712, \$1713)  
For description, see 1711, 1712, 1713.
- 3811, 3812, 3813. INTRODUCTION TO HISTORY OF SCIENCE.** (4 cr per qtr, \$1811, \$1812, \$1813)  
For description, see 1811, 1812, 1813.
- 3825. PHYSICS AND SOCIETY IN 20TH-CENTURY AMERICA.** (4 cr, \$3835, \$5825) Stuewer  
Nineteenth-century heritage; 20th-century discoveries and physical theories; growth of physics in America after World War I: the intellectual migration of the 1930s; nuclear physics, the Manhattan project, and the atomic bomb; McCarthyism and Oppenheimer; current and past contributions of Minnesota physicists.
- 3835. THE ATOMIC AGE.** (4 cr, \$3825, \$5825) Stuewer  
Development of nuclear energy in the 20th century; construction and use of the bomb; postwar military and political impact.
- 5011. THEORIES OF LIGHT AND COLOR.** (4 cr) Shapiro  
Physical and physiological theories of light and color from the 17th century (Kepler, Descartes, Newton, Huygens) through the 19th century (Young, Fresnel, Maxwell, Helmholtz). Methodological and philosophical aspects.
- 5111. PHYSICAL SCIENCES IN ANTIQUITY.** (4 cr) Shapiro  
Mathematics and astronomy in Babylonia; Greek mathematics, Euclid and Archimedes; Aristotle's physics and cosmology; the emergence of mathematical and experimental natural science in Greece; Ptolemaic astronomy.
- 5201, 5202, 5203. HISTORY OF BIOLOGY.** (4 cr per qtr, \$3201, \$3202, \$3203)  
For description, see 3201, 3202, 3203.
- 5242. EVOLUTION BEFORE AND AFTER DARWIN.** (4 cr; prereq Biol 1011 or 1101 or #) Kottler  
Philosophical conceptions of species; natural theology, design, and providential creation of species; Lamarck and evolution before Darwin; catastrophist and uniformitarian geology; Darwin and the background of the *Origin*; Darwin's early critics; evolutionary theory, 1882 to modern synthesis.
- 5760. SELECTED TOPICS.** (1-5 cr per qtr; prereq #)
- 5825. PHYSICS AND SOCIETY IN 20TH-CENTURY AMERICA.** (4 cr, \$3825, \$3835) Stuewer  
For description, see 3825.
- 5924. HISTORY OF 19TH-CENTURY PHYSICS.** (4 cr, \$Phys 5924; prereq general physics or #) Stuewer  
Conceptual developments in physics in 19th century (Young, Fresnel, Oersted, Ampere, Faraday, MacCullagh, Maxwell, Hertz, Lorentz, Lavoisier, Rumford, Dalton, Mayer, Joule, Helmholtz, Carnot, Clausius, Kelvin, Boltzmann, Mach, others). Relationships to social, philosophical, and theoretical influences.
- 5925. HISTORY OF 20TH-CENTURY PHYSICS.** (4 cr, \$Phys 5925; prereq general physics or #) Stuewer  
Conceptual developments in relativity (Michelson, Lorentz, Poincaré, Einstein, others), quantum mechanics (Planck, Einstein, Rutherford, Bohr, Sommerfeld, Ehrenfest, Pauli, Millikan, Compton, Heisenberg, de Broglie, Schrödinger, Born, others), and nuclear physics (Chadwick, Gamow, Fermi, others). Relationships to social, philosophical, and theoretical influences.
- 5970. DIRECTED STUDIES.** (1-15 cr per qtr; prereq #)  
Guided individual reading or study.
- 5990. DIRECTED RESEARCH.** (1-15 cr per qtr; prereq #)

## 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, break-even 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; 5000 and ME 3900 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 decisions, and investment decisions.
- 5030. QUALITY CONTROL AND RELIABILITY.** (4 cr; prereq Math 1231, ME 3900 . . . I.EOR 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 . . . I.EOR 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.
- 5050. ENGINEERING ECONOMIC ANALYSIS.** (4 cr; prereq 5000 or #; 3 lect and 1 rec hrs per wk)  
Fundamental principles and techniques of economic analysis of engineering projects including economic measures of effectiveness, time value of money, cost estimation, depreciation, taxes, breakeven, replacement and investment analysis.
- 5180, 5181. APPLIED INDUSTRIAL ENGINEERING.** (3-5 cr [1-2 cr term paper option] ; prereq background in all basic industrial engineering areas [5000, 5010, 5020, 5030 and 5040] )  
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] ; 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 . . . background in all basic industrial engineering areas [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. Development of ability to recognize and diagnose industrial problems.
- 5361. INVENTORY AND PRODUCTION CONTROL.** (4 cr; prereq 5000, 5040, ME 3900; 3 lect and 1 rec hrs per wk)  
Forecasting techniques and 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 5040, Math 1231, ME 3900; 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, queuing theory, and simulation.
- 5445. TOPICS IN MANAGEMENT SCIENCE.** (3-5 cr [1-2 cr term paper option]; background in all areas of industrial engineering [5010, 5020, 5030 and 5040] recommended; 3 lect hrs per wk)

## Course Listings

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Specialized topics in management science. Analytical tools for decision making and management of the production function. Emphasis on topics appearing in the current literature. Topics change from quarter to quarter.

- 5531. INDUSTRIAL SAMPLING TECHNIQUES.** (4 cr; prereq 5030, ME 3900; 3 lect and 1 rec hrs per wk)  
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 3092 or Stat 5121 or Stat 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 5550, ME 3900; 3 lect and 1 rec hrs per wk)  
Experiments of two or more factors. Designs involving crossed, nested, and mixed classifications; orthogonal polynomials; block confounding; fractional factorial designs; and computer programs for analysis.
- 5701. TECHNOLOGY ASSESSMENT.** (4 cr; prereq upper division; 4 lect hrs per wk)  
Unintended consequences of specific technologies on society. The history, institutional structures, and methodology of technology assessment; specific technology assessments. One or more class projects.
- 5710. TRANSIT SYSTEMS ANALYSIS AND DESIGN.** (4 cr; prereq sr engineering status; 3 lect and 1 rec hrs per wk)  
Introduction to transit systems; performance and energy relationships; kinematical design of curved guideways; lateral suspension dynamics; performance and cost effectiveness of shuttle, loop, line haul, and network systems operating in scheduled and demand modes; patronage analysis.
- 5711. TRANSIT SYSTEMS ANALYSIS AND DESIGN.** (4 cr; prereq 5710; 3 lect and 1 rec hrs per wk)  
Design of transit vehicles for safe operation; reliability allocation in transit systems for minimum life cycle cost; theory of control of automated guideway transit systems; cost-effective design of guideway structures; synthesis and basic design requirements of transit systems for maximum cost and energy effectiveness.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8110-8111-8112. ADVANCED INDUSTRIAL ENGINEERING**
- 8310-8311-8312. PRODUCTION ENGINEERING PROBLEMS**
- 8410-8411-8412. INDUSTRIAL ENGINEERING RESEARCH**
- 8420. LINEAR PROGRAMMING**
- 8430. NONLINEAR PROGRAMMING**
- 8440. DYNAMIC PROGRAMMING**
- 8450. QUEUING THEORY**
- 8460. STOCHASTIC PROGRAMMING**
- 8470. ADVANCED INVENTORY AND PRODUCTION CONTROL**
- 8773-8774-8775. GRADUATE SEMINAR**

## 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.

- 1023a. 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; perception and our relationship to our environment; and the social effects and psychological basis for design.
- 1025. BASIC VISUALIZATION I.** (4 cr; 2 lect and 4 lab hrs per wk; prereq LA major or #)  
Perspective drawing, landscape sketching, visual analysis of landscape materials, presentation techniques for plans, sections, elevations, and diagrams.
- 1026. BASIC VISUALIZATION II.** (4 cr; prereq 1025; 6 studio hrs per wk)  
Students continue to refine their ability to execute acceptable line drawings developed in 1025 and to develop their own techniques. Continued emphasis on perspective sketching, color sense, psychology of graphic interpretation, mixed media, and printing reproduction processes.
- 1031. INTRODUCTION TO LANDSCAPE ARCHITECTURE.** (4 cr; 4 lect hrs per wk)  
Design potential of materials of the landscape, exercises in assessment of land developments and detail landscapes; the role of the landscape architect in shaping the natural and cultural environment; brief historical review of site developments.
- 3071. LANDSCAPE TECHNOLOGY: GROUND FORM DESIGN.** (4 cr; prereq 3083, CE 3100, AgEn 1400; 2 lect and 6 lab hrs per wk)  
Lectures, exercises, and projects in ground form manipulation, earthwork computation and surface drainage techniques.
- 3072. LANDSCAPE TECHNOLOGY: CIRCULATION AND UTILITIES DESIGN.** (4 cr; prereq 3071 and 3091; 2 lect and 6 lab hrs per wk)  
Lectures, exercises, and projects in layout of circulation and landscape utilities systems.
- 3073. LANDSCAPE TECHNOLOGY: LAND ANALYSIS TECHNIQUES.** (4 cr; prereq 3072; 2 lect and 6 lab hrs per wk)  
Lectures, exercises, and projects in land analysis techniques for use in assessment of land development potential.
- 3075. LANDSCAPE TECHNOLOGY: MATERIALS AND CONSTRUCTION DESIGN.** (4 cr; prereq 3072 and 3092; 2 lect and 6 lab hrs per wk)  
Lectures, exercises, and project 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 to expand awareness of the design potential of the environment, develop processes and graphic techniques for problem solving, develop 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 the design potential of natural land materials, landscape survey and analysis techniques, elements of the environment as they condition design potential, methodologies for solving design problems, 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.** (4 cr; prereq 1025 and 3082; 2 lect and 6 lab hrs per wk)  
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, §FR 5233; 4 lect hrs per wk)  
For advanced students interested in design, management, and planning of recreational facilities. Planning and design principles related to recreational land use and development; parks, campsites, water areas, highways, summer and winter recreational facilities.
- 5101. SITE PLANNING AND DESIGN.** (6 cr; prereq 3093; 2 lect and 12 lab hrs per wk)  
Case study analysis and design of site organizational systems.
- 5103. URBAN LANDSCAPE DESIGN.** (6 cr; prereq 3093; 2 lect and 12 lab hrs per wk)  
Case study analysis and design of urban environments.

## Course Listings

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- 5105. RECREATIONAL PLANNING AND DESIGN.** (6 cr; prereq 5010; 2 lect and 12 lab hrs per wk)  
Analysis development and presentation of landscape design solutions for diverse recreational land use.
- 5107. REGIONAL LANDSCAPE DESIGN.** (6 cr; prereq 3092; 3 lect and 12 lab hrs per wk)  
Emphasis 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 of study; 2 lect and 12 lab hrs per wk)  
Advanced studies in area of student's option.
- 5117. PLANTING DESIGN SEMINAR: AESTHETIC PRINCIPLES.** (2 cr; prereq 3081 and Hort 1021)  
Lectures, presentations, field trips, and readings exploring aesthetic design principles and philosophies related to the use of plant materials in the landscape. Historic examples related to design principles, and philosophies or styles of expression.
- 5118. PLANTING DESIGN SEMINAR: PLANTS FOR FUNCTIONAL PURPOSES.** (2 cr; prereq 3092)  
Lectures, presentations, readings, and field trips focusing on development of planting designs and specifications; maintenance concerns.
- 5119. PLANTING DESIGN SEMINAR: ECOLOGICAL PRINCIPLES OF PLANTING DESIGN.** (2 cr; prereq 3093)  
Lectures, presentations, field trips, and readings related to the principles and practices of using plant materials in an ecologically sound and environmentally sensitive manner. Prairie, north woods, riverine, and wetland environments. Use of naturalized materials for such purposes as highway planting.
- 5131-5132-5133. SELECTED PROBLEMS IN LANDSCAPE ARCHITECTURE.** (Cr ar; prereq #)
- 5224. CONTEMPORARY ISSUES IN LANDSCAPE ARCHITECTURE.** (4 cr; prereq terminal yr of study; 4 discussion hrs per wk)  
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.
- 5225. LANDSCAPE TECHNOLOGY: WORKING DRAWINGS AND SPECIFICATIONS.** (4 cr; prereq 3072; 3 lect and 3 lab hrs per wk)  
Lectures, exercises, and projects in working drawing and specification 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.
- 5261. HISTORY OF LANDSCAPE ARCHITECTURE: SEMINAR I.** (2 cr; prereq first-yr LA student; 2 discussion hrs per wk)  
History as a resource for the landscape architect; historic perspective on use of elements such as line, texture, form, water, stone/earth, and vegetation.
- 5263. HISTORY OF LANDSCAPE ARCHITECTURE: SEMINAR II.** (2 cr; prereq second yr-LA student; 2 discussion hrs per wk)  
Historical perspective on functional use of space at the micro and macro scales; theories of space organization from medieval through modern periods; mood, place, intimacy, and security as design elements viewed in historic perspective.
- 5265. HISTORY OF LANDSCAPE ARCHITECTURE: SEMINAR III.** (2 cr; prereq third-yr LA student; 2 discussion hrs per wk)  
Works of key landscape architects and concepts and theories that influenced their designs. Integration of design concepts into the design process.

## Mathematics (Math)

- 0006. ELEMENTARY ALGEBRA** (See *Extension Classes Bulletin*)
- 0007. PLANE GEOMETRY.** (See *Extension Classes Bulletin*)
- 0008. SOLID GEOMETRY.** (See *Extension Classes Bulletin*)
- 0009. PREPARATORY MATHEMATICS.** (See *College of Liberal Arts 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*)
- 1131f,w,s. FINITE MATHEMATICS.** (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, 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.
- 1211f-1221w-1231s. ANALYSIS I-II-III.** (5 cr per qtr; prereq grade of C or better in 1201 or high school higher algebra, trigonometry, geometry, and math 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.
- 1311f-1321w-1331s. 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 math placement score for 1311...grade of C or better in 1311 for 1321...grade of C or better in 1321 for 1331)  
Content essentially the same as 1211-1221-1231 and 1611-1621, plus topics in elementary computer programming. Calculus from a computer point of view.
- 1511f-1521w-1531s. HONORS CALCULUS.** (5 cr per qtr; prereq  $\Delta$ )  
Calculus of functions of one variable with emphasis on theory. Emphasis on basic concepts and proofs. Computational aspects.
- 1611f-1621w. ANALYSIS I-II.** (5 cr per qtr; prereq 4 yrs high school math incl trigonometry and  $\Delta$  for 1611...grade of C or better in 1611 for 1621)  
Accelerated sequence for high ability students (continued in 3611-3621). Covers content of 1211-1221-1231.
- 3057. ACTUARIAL SCIENCE PRINCIPLES.** (See *College of Liberal Arts Bulletin*)
- 3066f,w,s. ELEMENTARY DIFFERENTIAL EQUATIONS.** (4 cr, §3221, §5512, §5521; prereq 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 humankind; prereq 1331 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 1311 or equiv)  
Euclidean geometry: ruler and compass constructions and theorems on triangle and circle not studied in high school plane geometry.
- 3211f,w,s. ANALYSIS IV.** (5 cr, §3521; prereq 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 grade of C or better in 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.
- 3231f,w,s. VECTOR ANALYSIS.** (4 cr, §5601-5602; prereq 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.
- 3511. ANALYSIS IV.** (5 cr, §3142, §3221; primarily for math majors in IT and 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.
- 3521w. ANALYSIS V.** (5 cr, §3211; primarily for math majors in IT and 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.
- 3531s. ANALYSIS VI.** (5 cr, §3675; primarily for math majors in IT and in the College of Education; prereq 3521)  
(Continuation of 3521) Differential equations, vector analysis.

## Course Listings

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- 3581f. FOUNDATIONS OF ARITHMETIC.** (4 cr; prereq 3211)  
Sets, relations, order. Real number system. Continuous functions.
- 3582w. FOUNDATIONS OF ALGEBRA.** (4 cr; prereq 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.
- 3611s. MULTIVARIABLE CALCULUS.** (5 cr; prereq 1621)  
Vector functions, partial derivatives, gradient, chain rule, directional derivatives, higher partial derivatives, max-min problems, multiple integrals, cylindrical and spherical coordinate systems.
- 3621f. LINEAR MATHEMATICS.** (5 cr; prereq 3611)  
First- and second-order differential equations, linear differential equations with constant coefficients. Undetermined coefficients, variation of parameters. Linear algebra: vectors in  $n$ -dimensions, linear systems of equations, Gaussian elimination, matrix algebra.
- 3631w. LINEAR MATHEMATICS.** (5 cr; prereq 3621)  
Linear algebra: vector spaces, subspaces, linear independence, bases, rank, nullity, linear transformations, matrices, matrix inversion, characteristic polynomial eigenvalues. Review of multivariable calculus. Differentiation of vector valued functions in a linear algebra setting.
- 3675f,w,s. INTRODUCTORY MATHEMATICS.** (4 cr, §3531; prereq 1231 or 1331 or equiv)  
Designed to prepare sophomore mathematics majors for the theoretical courses they will encounter during the junior and senior years.
- 5070. TOPICS IN THE HISTORY OF MODERN MATHEMATICS.** (4 cr [may be repeated for cr with  $\Delta$ ]; prereq one 5xxx mathematics sequence or equiv)  
Mathematical developments within the last 200 years.
- 5090. CALCULUS REFRESHER.** (See *Extension Classes Bulletin*)
- 5151f. ELEMENTARY SET THEORY.** (4 cr; prereq 3211)  
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)  
Sets and relations; statement calculus; Boolean algebra; predicate calculus, models, validity and truth; examples of first-order theories as illustrations of the axiomatic method; the completeness theorem, the incompleteness theorem, and metamathematics (discussion only).
- 5162f-5163w-5164s. MATHEMATICAL LOGIC.** (4 cr per qtr; prereq 3211 with 3221 or 3211 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  $\Delta$ ]; prereq #)  
Topics vary from quarter to quarter.
- 5209w,s. THEORY OF NUMBERS.** (4 cr; prereq 3211)  
Elementary properties of integers; prime and composite numbers; Euclidian algorithm; congruences; theorems of Fermat and Wilson; primitive roots; indices; Diophantine equations.
- 5232w-5233s. COMPUTER-ORIENTED LINEAR ALGEBRA.** (4 cr per qtr, §5242-5243, §5283-5284; prereq 3221 or 3142 or 3511)  
Linear transformations on finite dimensional vector spaces. Linear dependence, matrix algebra, inner products, orthogonality, and matrix inversion presented from algorithmic viewpoint, with students constructing and running illustrative computer programs. Eigenvalues and eigenvectors, Jordan canonical form, polar representation of linear transformations, determinants.
- 5242f-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-5283w,s-5284f,s. FUNDAMENTAL STRUCTURES OF ALGEBRA.** (4 cr per qtr, §5244 for 5282; principally for students planning grad work with a major in mathematics; prereq 3675, 3221 or 3142 or 3511)  
Theory oriented. Group theory: normal subgroups, homomorphisms, 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  $\Delta$ ]; prereq #)  
Topics vary from quarter to quarter.

- 5341f,w-5342w,s. INTRODUCTION TO TOPOLOGY.** (4 cr per qtr; prereq 3675, 3211 or 3521)  
Set theory; axiom of choice, Zorn lemma. Metric spaces: completeness, compactness, continuity. Basic point set topology: countability and separation axioms, Urysohn 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.
- 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.
- 5386f-5387w-5388s. FUNDAMENTAL STRUCTURES OF GEOMETRY.** (4 cr; prereq 5242 or 5282)  
A modern treatment of geometry based on the methods of abstract algebra: vector methods in geometry, Affine and projective geometries. Groups of affine and projective transformations. Quadratic forms and metrics. Witt theorem. Orthogonal and rotation groups. Cartan-Diendoné theorem. Euclidean and non-Euclidean geometries and their groups.
- 5404w. VARIATIONAL PROBLEMS.** (4 cr; prereq 5602 or 5512 or #)  
Euler-Lagrange equations, isoperimetric problems, geodesics, Fermat and Hamilton principles, methods of Rayleigh-Ritz, eigenvalues and eigenfunctions.
- 5427w. APPLIED MATHEMATICS FOR THE LIFE SCIENCES.** (4 cr; prereq 3211, 3221 or #)  
Mathematical tools useful in deterministic models arising in life sciences. Linear systems of difference and differential equations. Stability of nonlinear systems, including linearization techniques and Liapunov theory. Examples from demography, population ecology, and population genetics.
- 5428s. MATHEMATICAL MODELS IN ECONOMICS AND THE SOCIAL AND MANAGEMENT SCIENCES.** (4 cr; prereq 3211 with 3221 or 3511, 3521, 3531 or equiv)  
Mathematical models and associated mathematical techniques for describing behavior and optimization of various systems. How to find a model for a given situation.
- 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 for various subfields of fluid mechanics, hydrostatics, 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, 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.
- 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 WITH APPLICATIONS I.** (4 cr; prereq 3211 or 3521 or 3611, 3221 or 3066 or 3531 or 3621)  
Applications, review of special techniques, and numerical approximation for first-order equations. Euler and Runge-Kutta methods with error analysis. Applications and power series solutions for second-order equations.
- 5513. DIFFERENTIAL EQUATIONS WITH APPLICATIONS II.** (4 cr; prereq 5512)  
Applications and Laplace transforms for second-order linear equations. First-order linear systems with elementary linear algebra. Phase plane analysis with applications. Boundary value problems and an introduction to partial differential equations.
- 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; Poincaré-Bendixson theory, linear and nonlinear oscillations; stability theory; asymptotic behavior of solutions; control theory. 5523: Formal convergence of power series solutions majorant method; regular and irregular singular points; error estimates perturbation methods.

## Course Listings

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- 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 3231 or 5602 or equiv course in vector analysis)  
Derivative and integral of a function of a complex variable. Cauchy 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 equations.
- 5571f-5572w-5573s. ELEMENTARY PARTIAL DIFFERENTIAL EQUATIONS.** (4 cr per qtr, §5568 for 5572 and 5573; 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 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  $\Delta$ ]; prereq #)  
Topics vary from quarter to quarter.
- 5601f,w-5602w,s-5603s. ADVANCED CALCULUS.** (4 cr per qtr; prereq 3211)  
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.
- 5611. VECTOR FUNCTIONS.** (4 cr; prereq 3631)  
Vector analysis, line integrals, divergence and Gauss theorem, Stokes theorem. Applications of linear algebra to systems of differential equations.
- 5612f-5613w-5614s. INTRODUCTION TO ANALYSIS.** (4 cr per qtr; principally for students planning grad work with a major in mathematics, as preparation for grad courses in analysis; prereq 3675, 3521 or 3211 with 3221 or 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 #)  
Basic limit theorems. Comparison with Riemann integral. Lebesgue measure. Absolute continuity.
- 5625s. DEVELOPMENT OF NUMBER SYSTEMS.** (4 cr, §5612; prereq 3211)  
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.
- 5679. PROBABILITY.** (4 cr, §5681; prereq 3211 or 3521)  
Elementary principles of probability, total and compound probability, expectation, repeated trials. As time permits, topics chosen from Stirling 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. INTRODUCTION TO COMBINATORICS.** (4 cr; prereq 3211 and 3rd-yr standing... soph-level linear algebra is helpful)  
Basic concepts. Enumeration including binomial counting, permutations, generating functions, inclusion-exclusion principle, recurrence relations. Emphasis on application. Introduction to matching theory and designs.
- 5702w. INTRODUCTION TO GRAPH THEORY.** (4 cr; prereq 3211 and 3rd-yr standing... soph-level linear algebra is helpful)  
Basic concepts. Topics from connectedness, Eulerian graphs, trees, matrices, Hamiltonian graphs, coloring problems, plane graphs, enumeration. Applications may be discussed.
- 5703s. COMBINATORIAL ALGORITHMS AND OPTIMIZATION.** (4 cr; prereq 3211 or equiv and knowledge of some programming language)  
An introduction to basic algorithmic methods in combinatorics with emphasis on optimization.
- 5900. TUTORIAL COURSE IN ADVANCED MATHEMATICS.** (Cr ar; prereq #)  
Qualified students may make arrangements to study content of other graduate courses.

**5910. PROBLEMS COURSE.** (4 cr [may be repeated for cr with  $\Delta$ ]; prereq #)

Problem-solving techniques in many areas of mathematics. Topics from elementary to advanced levels, adapted to students of varied backgrounds.

**FOR GRADUATE STUDENTS ONLY**

(For course descriptions, see the *Graduate School Bulletin*)

- 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
- 8351-8352-8353. GLOBAL ANALYSIS
- 8360-8361-8362. TOPICS IN TOPOLOGY
- 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
- 8530-8531. 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

## Course Listings

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- 8590-8591-8592. TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS
- 8600-8601-8602. REAL ANALYSIS
- 8609-8610. THEORY OF DIFFERENTIATION
- 8624-8625-8626. GENERALIZED FUNCTIONS, 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 THEORY AND PROBABILITY
- 8660-8661-8662. STOCHASTIC PROCESSES
- 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 QUASI-CONFORMAL 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. TOPOLOGICAL 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 and Aerospace Engineering, School of (SMAE)

- 3200. **INTRODUCTION TO ENGINEERING FLUID MECHANICS.** (4 cr, §CE 3400; prereq Math 3221)  
The flow of viscous incompressible fluids; fluid statics, Bernoulli flow, momentum conservation, laminar and turbulent pipe flow, laminar and turbulent boundary layers.
- 5710. **TRANSIT SYSTEMS ANALYSIS.** (4 cr; prereq sr or grad student; 4 lect hrs per wk)  
Fundamental analysis of characteristics and requirements for alternative transit systems: classification and descriptions of alternative transit systems, performance relationships, cost effectiveness, requirements for safe operation, reliability, maintainability, factors influencing patronage, benefits analysis, technological issues. Designed to prepare students for professional work in planning and engineering conventional and new types of transit.

## Mechanical Engineering (ME)

- 1001. **INTRODUCTION TO MECHANICAL ENGINEERING.** (1 cr; S-N only; 1 lect hr per wk)  
An introduction to the field presented by practicing engineers and members of the faculty. Topics include the mechanical engineering curriculum, the elective program, the profession, and related areas of research.

- 3201. MECHANICAL ENGINEERING SYSTEMS ANALYSIS.** (4 cr, §AEM 3401; prereq AEM 3036; 3 lect and 2 lab hrs per wk)  
Determination of response of engineering systems utilizing transfer function representation. Analogies between engineering systems based upon transfer function equivalence.
- 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 electromechanical components. Energy balance techniques used to describe energy flow through machine systems.
- 3205. ENGINEERING SYSTEMS DESIGN.** (4 cr; prereq AEM 3016; 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. Vapor cycles, gas engine cycles, propulsion systems, refrigeration and air-water vapor mixtures.
- 3305. PROPULSION THERMODYNAMICS.** (4 cr, §3303; prereq 3301 and 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.
- 3402. ECOLOGY, TECHNOLOGY, AND SOCIETY.** (4 cr, §SSci 3402; 4 lect hrs per wk)  
Problems relating technology, society, and nature. The growth of technology, current technological issues, population growth, resource limits, ecological balance, growth dilemma, technological imperative, ethics and values, control of technology, appropriate technologies, alternative strategies.
- 3701-3702. BASIC MEASUREMENTS LABORATORY I AND II.** (2 cr per qtr; prereq 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.
- 3703-3704-3705. ADVANCED MECHANICAL ENGINEERING LABORATORY.** (2 cr per qtr; 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 two 5-week laboratory modules as selected by the student.
- 3740. INDUSTRIAL ASSIGNMENT.** (2 cr [may be repeated for cr]; prereq regis in intern program)  
Industrial work assignment in engineering intern program. Grade based on formal written report written by the student covering the quarter's work 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)  
Special investigations in various fields of mechanical engineering and related areas including an independent study project.
- 5203. ADVANCED ANALYSIS AND SYNTHESIS OF MECHANISM SYSTEMS.** (3-4 cr; prereq 3203 or equiv... computer programming desirable; 3 lect hrs per wk)  
Analytical methods of kinematic, dynamic, and kinetoelastodynamic analysis and synthesis of mechanisms. Computerized design for function, path and motion generation based on Burmaster theory.
- 5205. CREATIVITY IN ENGINEERING DESIGN.** (3-4 cr [1 cr term paper option]; completion of ME core courses or equiv desirable; 3 lect hrs per wk)  
The role of creative action at various stages in 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.

## Course Listings

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- 5220. COMPUTER-AIDED DESIGN.** (4 cr; prereq 3rd-yr ME courses and FORTRAN programming; 3 lect and 1 rec hrs per wk)  
Application of computer-aided design techniques to engineering design. Engineering design projects/case studies utilizing selected computerized numerical techniques, design optimization, and computer graphical presentation of results.
- 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; completion of 3rd-yr basic engineering courses desirable; 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; 1 lect and 2 lab sessions per wk)  
Participation in solution of systems design problems that have developed criteria, order-of-magnitude evaluation of alternatives, and generation of 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. Material processing including machining, welding, and deformation processes.
- 5262. MATERIAL WORKING AND FABRICATION PROCESSES.** (4 cr; prereq 5260 or equiv; 3 lect and 1 rec hrs per wk)  
Theory and application of joining techniques, welding, brazing, and adhesive bonding. Metal forming, rolling, swaging, drawing, and similar operations. Inspection and test methods to control and evaluate fabrication processes including X-ray, magnetic, metallographic, and chemical methods.
- 5264. MATERIAL CONSOLIDATION PROCESSES.** (4 cr; prereq 5260 or equiv; 3 lect and 1 rec hrs per wk)  
Theory and practice of material consolidation including casting and powder metal processes. Composite materials techniques.
- 5266. MATERIAL 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; 3 lect and 1 rec hrs per wk)  
Fundamental properties of engineering materials including fabrication, treatment, physical and corrosive properties. Failure mechanism, cost and value analysis as related to material 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 electromechanical components. On-off, proportional, floating, and rate response in control systems, including industrial instrumentation.
- 5342. HEAT TRANSFER.** (4 cr; prereq 3301 and CE 3400 or SMAE 3200; 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 3301 and CE 3400 or SMAE 3200; 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 cr 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, fan-jet and turboprop engine performance.
- 5480. BIOLOGICAL FLUID FLOW.** (3-4 cr [1 cr term paper option]; prereq CE 3400 or equiv; 3 lect hrs per wk)  
Introduction to rheology and fluid dynamics of biological fluids. 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 and 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 3303 and CE 3400 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, and control, handling, and disposal of solid waste.
- 5613. PRINCIPLES OF PARTICLE TECHNOLOGY.** (4 cr; 3303 desirable; 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.
- 5615. AIR CONTAMINANT MEASUREMENT.** (4 cr; prereq 5613 or #)  
Principles of operation, application and interpretation of data from instruments and instrument systems used for in-plant contaminants, emissions and air quality measurement.
- 5712. SOLAR ENERGY UTILIZATION.** (4 cr; prereq 5342 or #; 4 lect hrs per wk)  
History and potential of solar energy utilization; availability of solar radiation on clear and cloudy days; incident radiation on horizontal, vertical, and inclined surfaces; flat-plate and concentrating solar collectors; heating and cooling with solar energy; power generation; review of current research.
- 5721. PROPULSIVE SYSTEMS FOR SURFACE TRANSPORTATION.** (4 cr; intended for engineering srs; 3301 recommended; 4 lect hrs per wk)  
Characteristics of electrical and mechanical propulsion devices and energy storage systems available for use in various types of surface transport vehicles, worldwide energy sources, environmental implications of transport propulsive devices, power requirements, and thermodynamic constraints.

## Course Listings

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### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 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
- 8351. COMPUTATION OF FLUID FLOW AND HEAT TRANSFER
- 8352. ADVANCED COMPUTATION OF FLUID FLOW AND HEAT TRANSFER
- 8353. COMPUTATION OF BOUNDARY LAYER FLOWS
- 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)

- 3090, 3091, 3092. INDUSTRIAL EMPLOYMENT. (1-2 cr per qtr [depending upon duration of employment])  
Employment with industrial firms that perform metallurgical or materials engineering activities. Report covering work required.
- 3400. MECHANICAL PROPERTIES OF MATERIALS. (4 cr; prereq 2nd-yr IT student; 3 lect and 1 rec or 2 lab hrs per wk)  
Introduction to the structure-property relationships of metals, alloys, and polymers. Crystal structure, diffusion, and the theoretical basis of elasticity and plasticity will be related to practical topics. Includes materials processing laboratory/recitation with emphasis on engineering alloys and heat treatment.
- 3501. QUANTITATIVE METALLOGRAPHY AND ELECTRON MICROSCOPY. (3 cr: 1 lect, 1 rec, and 2 lab hrs per wk)  
Microstructure of materials, temperature measurement and control, equilibrium diagrams, quantitative metallography, electron microscopy.

- 3521. X-RAY METALLOGRAPHY.** (3 cr; 1 lect, 1 rec, and 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 per qtr; prereq 3rd-yr IT student)  
Relationship between atomic structure and basic properties of metals, semiconductors, glasses, polymers, ceramics, and composites. 5011: Physical properties. 5012: Mechanical properties. 5013: Electrical and magnetic properties.
- 5101. THERMODYNAMICS AND MATERIALS STATES.** (4 cr; prereq ChEn 5101; Chem 5534 or #; 3 lect and 2 rec hrs per wk)  
(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 discussed in terms of dislocation behavior, creep, fatigue, fracture toughness, Control of mechanical properties through manipulation of microstructure in metal processing; drawing, forging, rolling, and forming processes.
- 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 per qtr; 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; 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. POLYMER CHEMISTRY.** (4 cr; prereq physical chemistry or 5011 or #; 3 lect and 3 lab hrs per wk)  
Polymer synthesis and physical chemistry: polymerization kinetics and reactors, molecular weight distribution, network formation, macromolecules in solution and their characterization, the glassy and crystalline state, rubber elasticity, flow and viscoelasticity, environmental degradation.
- 5620. POLYMER PROCESSING.** (4 cr; prereq engineering transport phenomena or #; 3 lect and 1 open lab-rec hrs per wk)  
Polymer processing principles and applications; rheology of long chain molecules, flow in simple geometries, die design, mixing, thermal properties, heat transfer and phase change; thermoplastic operations: extrusion, calendaring, forming and molding; thermoset operations.
- 5630. POLYMER PHYSICAL PROPERTIES.** (4 cr; prereq 5011 or 3400 and 5610 or Chem 5610 or #; 3 lect and 1 open lab-rec hrs per wk)  
Polymer structure-property relations: structure and morphology of the crystalline and amorphous state. Crystallization kinetics, vitrification and the glass transition, mechanical properties, failure, permeability, optical and electrical properties, polymer composites, effect of processing on properties.
- 5640. POLYMERIZATION REACTOR ENGINEERING.** (4 cr; prereq chemical engineering reactor design course or #; 3 lect hrs and 1 ar lab per wk)  
Introduction to the analysis and design of polymerization reactors. Topics include mathematical modeling techniques, chain growth and step growth polymerization, copolymerization, molecular weight distributions, composition and sequence distributions. Emphasis on application of results. Laboratory: experience with polymerization processes and molecular weight measurements.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8110. THERMODYNAMIC PROPERTIES OF SOLIDS: CLASSICAL AND STATISTICAL MECHANICS APPLIED TO STUDY OF THE PROPERTIES OF SOLIDS**

## Course Listings

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- 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 ALLOYS AND ORIGINS OF 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
- 8521. TOPICS IN ELECTRON MICROSCOPY
- 8522. ADVANCED X-RAY DIFFRACTION OF METALS

## Mineral Engineering (MinE)

- 5530. **FLUID FLOW THROUGH POROUS SOLIDS I.** (4 cr; prereq 5534 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 generalized equations; vertical flow; units. Kozeny equations derived; fracture and channel flow, electrical, acoustical, and radioactive properties of rocks pertaining to porosity and connate water of rocks. 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: EXPLORATION AND DEVELOPMENT.** (4 cr; prereq 3rd yr or #; 3 lect and 3 lab hrs per wk)  
Mineral distribution and demand; nongeologic ore determinants; mineral law, taxation, liquidation value; options and leases; ore guides; drilling, sampling, and combining theory; geostatics and concepts of risk elimination.
- 5612. **MINERAL RESOURCES II: DEVELOPMENT AND PRODUCTION SYSTEMS.** (4 cr; prereq 3rd yr or #; 3 lect and 2 rec hrs per wk)  
Development and production systems for mineral properties. Essential criteria for design and selection of mining methods. Unit operations; drilling, blasting, loading, and hauling.
- 5613. **MINERAL RESOURCES III: EXAMINATION AND VALUATION OF MINERAL PROPERTIES.** (4 cr; prereq 5612 or Geo 1111 or #; 4 lect hrs per wk)  
Reasons for examination; geological, technical, economic, and political factors; mineral laws; sampling methods; various methods to calculate reserves including geostatistics, elementary accounting; determination of direct costs, taxes, depreciation, depletion, profitability; present worth, rate-of-return and discounted cash flow; financing methods.
- 5619. **ENGINEERING FIELD STUDY.** (3 cr; prereq sr or grad student in mineral or geological engineering 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 5613 and Geo 1111 and Stat 3091 or equiv)  
Unit operations of drilling, blasting, loading, hauling, and transportation of surface rocks and soils. Equipment productivity, selection, and cost estimation. Design of open pits and quarries. Economics, environment, and organization.

- 5640. INTRODUCTION TO ECONOMICS OF THE MINERAL INDUSTRIES.** (4 cr; prereq 5613 or #)  
Elementary principles of economics and applications to the mineral industries; developed areas versus underdeveloped areas; marginal ore production; markets and marketing of raw materials, and their peculiarities.
- 5642. THE MINERAL INDUSTRIES.** (4 cr; prereq 5613 or #)  
Minerals and the developing economies; minerals and modern industrial economics; minerals and international trade; gold and silver as monetary metals. Problems in the analysis of resources: mineral supply; secondary (scrap) supply; depletion, exhaustibility, and conservation. Quantitative economic analysis: interindustry; projecting and forecasting; computer applications; marketing; mineral financing.
- 5650-5652. MINERAL ENGINEERING DESIGN I, II.** (4 cr per qtr; prereq sr or grad student in mineral engineering; 12 design hrs per wk)  
Systems approach to selected aspects of a mining project; exploration, mining, mineral processing, metals extraction. Integration of classroom concepts. Cost estimation and economic evaluation. Preparation of report on case example chosen by student.
- 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 5613, 5820, and GeoE 5437 or #; 3 lect and 2 rec hrs per wk)  
Introduction to systems analysis, operations research techniques, modeling and simulation. Applications in mineral engineering. Life cycle concept of mining.
- 5710. ENVIRONMENTAL ASPECTS OF MINERAL ENGINEERING.** (4 cr; prereq 5613 and 5820 or #; 4 lect hrs per wk)  
Recognizing and minimizing the environmental problems posed by mining and metallurgical operations. Both the immediate working environment and the larger ecological impacts are considered.
- 5720. MINERAL PLANT ENGINEERING I.** (4 cr; prereq 5612 or #; 3 lect and 3 lab hrs per wk)  
Basic engineering principles in design and selection of mine, petroleum, and mill plant equipment. Calculations involving compressed air, pumping, transmission of gases and fluids, and power systems—mechanical, hydraulic, pneumatic, and electrical.
- 5722. MINERAL PLANT ENGINEERING II.** (4 cr; prereq 5720 or #; 3 lect and 3 lab hrs per wk)  
Basic engineering principles in design and selection of mine plant equipment such as hoists, conveyors, and railroad systems. Calculations involving power transmission, drilling, hoisting, and transportation of crushed ore material.
- 5800. MINERAL PROCESSING I.** (4 cr; prereq #; 3 lect and 3 lab hrs per wk)  
Application of physical and chemical principles to mineral processing problems. Screening, size, reduction, size and gravity classification, electrical separation, and magnetic separation.
- 5810. MINERAL PROCESSING II.** (4 cr; prereq #; 3 lect and 3 lab hrs per wk)  
Chemical, physical, and engineering aspects of flotation, hydrometallurgy, thickening and filtration. Integration of operations and processes on a plant basis.
- 5815. MINERAL PROCESSING III.** (3 cr; 2 lect hrs and one 3-hr tutorial per wk; prereq 5800, 5810 or #)  
Simpler mathematical models currently used to simulate the operation of tumbling mills, hydrocyclones, flotation cells, and magnetic separators. Basic process control concepts. Types of process sensors currently used in industry.
- 5818. HYDROMETALLURGY.** (4 cr; prereq #; 3 lect and 3 lab hrs per wk)  
Application of physicochemical principles to leaching of metals, ores, and concentrates; to purification of leach solutions; to recovery of metals. Integration of operations and processes on a plant basis.
- 5820. PRINCIPLES OF METALS EXTRACTION I.** (4 cr; prereq 8 cr of 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. METALLURGICAL HEAT TRANSFER AND FLUID FLOW.** (4 cr; prereq 5820 or #; 4 lect hrs per wk)  
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 that control beneficiation processes.
- 5910. METALLURGICAL UNIT PROCESSES.** (5 cr; prereq 5825 or #)  
Unit processes of chemical metallurgy; roasting, agglomeration, smelting, converting, refining, vaporization, and electrolytic methods.

## Course Listings

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**5920. METALLURGICAL PROCESSES.** (2 cr; prereq 5820 or #; 4 lect and 4 lab hrs per wk)

The unit processes of extractive metallurgy are combined to illustrate the known technologies for producing metal from ore. Both ferrous and nonferrous applications and recent innovations in the field are stressed.

**5940. SPECIAL PROBLEMS IN EXTRACTIVE METALLURGICAL ENGINEERING.** (Cr and hrs ar; prereq sr)

Laboratory investigation of problems in extractive metallurgy.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

**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**

**8641. SELECTED MINERALS IN NATIONAL AND WORLD AFFAIRS**

**8724. MINE ENVIRONMENT ENGINEERING**

**8730-8732. OPERATIONS ANALYSIS IN MINERAL ENGINEERING I, II**

**8830. ELECTRIC AND MAGNETIC SEPARATION OF MINERALS**

**8832. TECHNIQUES OF MINERAL PROCESSING RESEARCH**

**8838-8839. OPTIMIZATION AND CONTROL TECHNIQUES IN MINERAL PROCESSING I, II**

**8840. FLOTATION THEORY**

**8842. SURFACE CHEMISTRY OF MINERAL SUSPENSIONS**

**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)

**1004. PHYSICAL WORLD, PHYSICS.** (4 cr, §any other physics courses; prereq 1 yr high school algebra; 3 lect and 1 problem hrs per wk)

Topics illustrate the methods of science and acquaint students with the physical universe.

**1005. PHYSICS LABORATORY.** (1 cr; S-N only; prereq 1004 or ¶1004; 2 lab hrs per wk)

Laboratory offered in conjunction with 1004.

**1031-1032. INTRODUCTORY PHYSICS: MEASUREMENT AND APPLICATIONS.** (4 cr per qtr, §other introductory physics courses; prereq high school algebra and plane geometry; 4 class hrs per wk)

Lectures and problem sessions. Application of physics: mechanics, random processes, gases and fluids, electric circuits, waves, light, optical instruments, atoms and spectra, nuclei, radioactivity. Primarily for students interested in topics useful in technical areas.

**1035-1036. INTRODUCTORY PHYSICS LABORATORY.** (1 cr per qtr; S-N only; prereq 1031 or ¶1031 for 1035. . . 1032 or ¶1032 for 1036; 2 lab hrs per wk)

Laboratory experiments offered in conjunction with 1031-1032.

**1061. PHYSICS OF HUMAN MOTION.** (3 cr; prereq 1 yr high school algebra, ¶1065; 3 lect-discussion hrs per wk)

Basic concepts of classical mechanics applied to motion of human bodies in various forms of work, athletics, and dance. Physics of muscles. Eight labs, five in gym.

**1065. HUMAN MOTION LABORATORY.** (1 cr; S-N only; prereq ¶1061; 2 lab hrs per wk)

Human motion experiments to accompany 1061.

**1071. INTRODUCTORY METEOROLOGY.** (4 cr; prereq high school algebra and trigonometry; 4 lect hrs per wk)

Physics of atmospheric processes. Clouds, fronts, and cyclones. Weather forecasting. Human influence on the atmosphere.

**1075. INTRODUCTORY METEOROLOGY LABORATORY.** (1 cr; S-N only; prereq 1071 or ¶1071; 2 lab hrs per wk)

Field experiments offered in conjunction with 1071.

- 1104-1105-1106. GENERAL PHYSICS.** (4 cr per qtr; prereq Math 1142 and high school trigonometry or Math 1008 for 1104; 4 lect and 1 quiz hrs per wk)  
Primarily for premedical and biological science students. 1104: Mechanics. 1105: Heat and electricity. 1106: Magnetism, sound, light, modern physics.
- 1107-1108-1109. GENERAL PHYSICS LABORATORY.** (1 cr per qtr; S-N only; prereq 1104-1105-1106 or ¶1104-1105-1106; 2 lab hrs per wk)  
Laboratory exercises offered in conjunction with 1104-1105-1106.
- 1121-1122. PHYSICS FOR ARCHITECTS.** (4 cr per qtr; prereq Math 1211 or ¶Math 1211; 4 lect hrs per wk)  
General principles of physics useful to prearchitecture students. Mechanics, heat, electric circuits, gases, light, sound, properties of materials.
- 1123-1124. PHYSICS FOR ARCHITECTS LABORATORY.** (1 cr per qtr; S-N only; prereq 1121-1122 or ¶1121-1122; 2 lab hrs per wk)  
Laboratory exercises offered in conjunction with 1121-1122.
- 1271-1281-1291. GENERAL PHYSICS.** (4 cr per qtr; prereq completion of or concurrent regis in Math 1221 or 1321 or 1621 or equiv for 1271; . . . completion of or concurrent regis in Math 1231 or 1331 or 1621 or equiv for 1281; may be taken with or without accompanying 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 offered in conjunction with 1271-1281-1291.
- 3011. OSCILLATIONS.** (4 cr; prereq 1291, Math 3221 or equiv; 3 lect and 1 prob hrs per wk)  
Physical and mathematical study of the harmonic oscillator. Transient behavior; resonance; impedance; mechanical and electrical examples; coupled systems; traveling and standing waves; Fourier series, interference.
- 3015. LABORATORY IN OSCILLATIONS AND WAVES.** (1 cr; prereq 3011 or ¶3011; 3 lab hrs per wk)  
Laboratory exercises in oscillations and waves.
- 3201. THERMODYNAMICS.** (4 cr; prereq 1281 or #; 3 lect and 1 prob session per wk)  
The laws of thermodynamics, entropy, and probability; applications to simple systems, phase equilibrium, chemical potential.
- 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.
- 3511-3512-3513. MODERN PHYSICS.** (4 cr per qtr; prereq 1291 or 1106 or ¶1291 or ¶1106, Math 1231 for 3511 . . . Math 3221 or 3066 or ¶Math 3221 or ¶3066 or equiv for 3512; 3 lect and 1 prob hrs per wk)  
Introduction to special relativity, statistical physics, quantum mechanics, and surveys of selected topics in atomic, molecular, solid state, nuclear and particle physics phenomena.
- 3515. PHYSICS LABORATORY.** (1 cr; prereq 3501 or ¶3501 or 3512 or ¶3512; 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 photographic processes. Image formation; intensity, color of illumination; exposure of photographic materials. Understanding technical literature as applied to pictorial photography (or tone reproduction); line reproduction and duplication.
- 3970. DIRECTED STUDIES.** (1-5 cr; prereq #,  $\Delta$ )  
Independent, directed study in physics in areas arranged by the student and a faculty member.
- 5021-5022.\* INTRODUCTION TO ANALYTIC MECHANICS.** (4 cr per qtr; prereq 3011, Math 3231 or equiv; 3 lect and 1 prob hrs per wk)  
Analytical course in Newtonian mechanics. Vectors and vector operators; central force problem; system of particles; tensors; rigid bodies; moving coordinate systems; continuous media; Lagrange equations. Mathematics beyond the prerequisites developed as required.
- 5023-5024.\* INTRODUCTION TO ELECTRIC AND MAGNETIC FIELDS.** (4 cr per qtr; 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 equations for free space and material media. Wave solutions.
- 5025.\* SPECIAL TOPICS IN ELECTRIC AND MAGNETIC FIELDS.** (4 cr; prereq 5024; 3 lect and 1 prob hrs per wk)  
Special topics selected by instructor.
- 5031-5032-5033.\* TOPICS IN MATHEMATICAL PHYSICS.** (4 cr per qtr; prereq two 5000-level math courses; 3 lect and 1 prob hrs per wk)  
Mathematical techniques needed for physics. Application of mathematical methods to physical problems.

## Course Listings

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- 5051-5052-5053.\* CLASSICAL PHYSICS.** (4 cr per qtr; prereq 5022 and 5024, advanced calculus or #; 3 lect and 1 prob hrs per wk)  
Classical mechanics, special relativity, and classical electrodynamics. Applications of advanced mathematical techniques.
- 5090. PHYSICS OF MUSICAL INSTRUMENTS.** (3 cr [may be repeated for cr with #, no cr for physics grad students], §MuEd 5750; prereq #)  
Seminar on physical characteristics of and processes in playing musical instruments. Nonmathematical; to improve performance and teaching skills. Electronic methods to sense and display cues to assist performance and teaching.
- 5091. PHYSICAL ACOUSTICS OF MUSIC.** (5 cr [no cr for physics grad students]; 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 instructor; 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.
- 5101-5102.\* INTRODUCTION TO QUANTUM MECHANICS.** (4 cr per qtr; prereq 3512; 3 lect and 1 prob hrs per wk)  
Mathematical techniques of quantum mechanics. Wave packets; Schrodinger equation, angular momentum; radial equation; spin; perturbation theory; collision theory.
- 5121. METHODS OF EXPERIMENTAL PHYSICS: I.** (5 cr; prereq 3513 or #. . . knowledge of FORTRAN programming desirable; 3 lect and 4 lab hrs per wk)  
Contemporary techniques. Includes probability and errors, introduction to analog and digital electronics, experimental strategy, and introduction to computer-based data acquisition and experimental control.
- 5122. METHODS OF EXPERIMENTAL PHYSICS: II.** (4 cr; prereq 5121 or #; 2 lect and 6 lab hrs per wk)  
Contemporary techniques. Includes applications of Fourier transforms, signal averaging and phase-lock detectors, high vacuum techniques, magnet and charged particle beam design. Laboratory: problems involving the use of microcomputers for data acquisition and experimental control.
- 5123. METHODS OF EXPERIMENTAL PHYSICS: III.** (4 cr; prereq 5122 or #; 8 lab hrs per wk)  
Contemporary techniques. Laboratory: choice of experimental projects in low temperature, solid state, nuclear, elementary particle, and cosmic ray physics.
- 5124. SENIOR EXPERIMENTAL PROJECT.** (Cr ar; prereq 5123 and #)  
Research project in some aspect of contemporary physics. Project must be approved by faculty coordinator prior to registration.
- 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, identical particles, applications to atomic systems.
- 5162.\* INTRODUCTION TO PLASMA PHYSICS.** (4 cr; prereq 5022 and 5024 or #)  
Magnetohydrodynamics and properties of collisionless plasmas, applications to magnetic field of earth and sun and to plasma confinement. Transport phenomena and effects of collisions.
- 5202-5203.\* STATISTICAL MECHANICS, TRANSPORT THEORY, AND IRREVERSIBLE PROCESSES.** (4 cr per qtr; prereq 3201 or #; 3 lect and 1 prob hrs per wk)  
5202: Equilibrium ensembles, quantum statistics, applications of statistical mechanics to interacting and noninteracting systems. 5203: Boltzmann equation and its applications, fluctuations and Brownian motion, irreversible processes.
- 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)  
Crystal structure and binding; diffraction; phonons; thermal and dielectric properties of insulators; free-electron model; band structure; semiconductors; diamagnetism; paramagnetism; ferromagnetism and antiferromagnetism; 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. Provides survey for nonspecialists; a 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.
- 5371.\* INTRODUCTION TO ELEMENTARY PARTICLE PHYSICS.** (4 cr; prereq 5102 or equiv; 3 lect and 1 prob hrs per wk)  
Relativistic kinematics; mass, spin, isospin, and strangeness of elementary particles; SU3 classification and the quark model; particle reactions and decays; experimental methods of detection and analysis.

- 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: characteristics, motion in interplanetary and interstellar medium. X-rays and radio astronomy
- 5441.\* INTRODUCTORY DYNAMIC METEOROLOGY I.** (5 cr; prereq 1291 and Math 3231 or 5602 or #: 3 lect and 3 lab hrs per wk)  
Fluid dynamics of large-scale weather systems; mathematical introduction to quasi-geostrophic model used in numerical weather prediction. Concurrent laboratory study of weather charts to illustrate application of theory offered.
- 5442.\* INTRODUCTORY DYNAMIC METEOROLOGY II.** (4 cr; prereq 5441 or #)  
Energetics and general circulation of the atmosphere.
- 5451.\* CLOUD PHYSICS.** (3 cr; prereq Math 3211 or equiv, 1 yr general physics; 3 lect 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.
- 5452.\* CLOUD SYSTEMS.** (3 cr; prereq Math 3211 or equiv, 1 yr general physics; 3 lect hrs per wk)  
Circulation, energy balance of atmosphere. Radar techniques for analyzing cloud systems. Cloud structure and motion.
- 5453.\* ELECTRICAL PROPERTIES OF CLOUDS.** (3 cr; prereq Math 3211 or equiv, 1 yr general physics; 3 lect hrs per wk)  
Structural, 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.
- 5461.\* PHYSICS AND CHEMISTRY OF THE EARTH'S UPPER ATMOSPHERE.** (4 cr; prereq general physics and calculus)  
Survey of atmosphere above 15 km; physics and chemistry of the stratosphere, mesosphere, and thermosphere; temperature and density profiles; major and minor constituents and their distributions; aspects of pollutants; reactions and rates; global variation of constituents; the energy budget of the atmosphere.
- 5551. TOPICS IN PHYSICS FOR BIOLOGY AND MEDICINE: MECHANICS AND MOLECULAR PHYSICS.** (5 cr per qtr; prereq general physics and calculus)  
Statics (forces in bones and joints). Graphical analysis. Statistical physics (entropy, reversibility, Boltzmann factor and Nernst equation, Brownian movement, free energy). Diffusion, bulk flow and osmosis.
- 5552. TOPICS IN PHYSICS FOR BIOLOGY AND MEDICINE: ELECTRICITY AND SIGNALS.** (5 cr per qtr; prereq general physics and calculus)  
Electricity and circuits (electrocardiogram, networks, nerve conduction); transducers, amplifiers; feedback and control; oscillators; signal analysis (Fourier analysis, correlation functions, power spectra).
- 5553. TOPICS IN PHYSICS FOR BIOLOGY AND MEDICINE: LIGHT, ATOMS, AND NUCLEI.** (5 cr per qtr; prereq general physics and calculus)  
Atoms (dispersion, absorption, spectra, polarized light). X-rays (production, absorption, dosimetry). Nuclei (nuclear size, mass, decay).
- 5801.\* MODERN OPTICS.** (4 cr; prereq 5024 or #: 4 lect hrs per wk)  
Modern theoretical and experimental optics, broadly defined to include, for example, radio astronomy. Matrix methods in geometrical optics including charged particle optics; optical detectors and noise; phenomena in intense coherent radiation including nonlinear effects.
- 5805.\* CONTEMPORARY OPTICS.** (4 cr; prereq #: 3 lect and 1 prob hrs per wk)  
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.
- 5924.\* HISTORY OF 19TH-CENTURY PHYSICS.** (4 cr; prereq general physics or #)  
Conceptual developments in physics in 19th century (Young, Fresnel, Oersted, Ampere, Faraday, MacCullagh, Maxwell, Hertz, Lorentz, Lavoisier, Rumford, Dalton, Mayer, Joule, Helmholtz, Carnot, Clausius, Kelvin, Boltzmann, Mach, etc.). Relationships of these developments to social, philosophical, and theological influences.
- 5925.\* HISTORY OF 20TH-CENTURY PHYSICS.** (4 cr; prereq general physics or #)  
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.). Relationships of these developments to social, philosophical, and theological influences.
- 5950. SENIOR SEMINAR.** (Cr ar; primarily for sr physics majors, Δ)

## Course Listings

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- 5801. MODERN OPTICS.** (4 cr; prereq 5024 or #; 4 lect hrs per wk)  
Modern theoretical and experimental optics, broadly defined to include, for example, radio astronomy. Matrix methods in geometrical optics including charged particle optics; optical detectors and noise; phenomena in intense coherent radiation including nonlinear effects.
- 5970. DIRECTED STUDIES.** (1-5 cr; prereq #,  $\Delta$ )  
Independent, directed study in physics in areas arranged by the student and a faculty member.
- 5990. DIRECTED RESEARCH.** (Cr ar; prereq 3rd yr,  $\Delta$ )  
Problems, experimental or theoretical, of special interest to students. Written reports.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8000.\* SEMINAR: THEORETICAL 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**
- 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**
- 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**
- 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.\* MAGNETOSPHERIC PHYSICS**
- 8440.\* SEMINAR: ATMOSPHERIC PHYSICS**
- 8445.\* ADVANCED TOPICS IN ATMOSPHERIC PHYSICS**
- 8481-8482-8483.\* ASTROPHYSICS**
- 8484.\* ORIGIN AND EVOLUTION OF THE SOLAR SYSTEM**
- 8500. PLAN B PROJECT**

8950.\* SEMINAR: PROBLEMS OF PHYSICS TEACHING AND HIGHER EDUCATION

8990.\* RESEARCH IN PHYSICS

## Statistics (Stat)

- 1051f,w,s. INTRODUCTION TO IDEAS OF STATISTICS.** (4 cr; prereq high school higher algebra)  
Presentation and analysis of data. Probabilistic models for inference. Inference and decision procedures. Emphasis on concepts rather than computation.
- 3091f,w,s. INTRODUCTION TO PROBABILITY AND STATISTICS.** (4 cr, §5121, §5131; prereq differential and integral calculus; one section designated primarily for IT majors)  
Elementary probability and probability distributions, sampling and elements of statistical inference. Treatment more mathematical than that in 1051.
- 5021f,w. STATISTICAL ANALYSIS I.** (5 cr; prereq college algebra or #)  
Frequency distributions; descriptive statistics; elementary probability; binomial, Poisson, and normal distribution; estimation and testing; analysis of variance; multiple comparisons; linear regression.
- 5022w,s. STATISTICAL ANALYSIS II.** (5 cr; prereq 5021 or #)  
(Continuation of 5021) Multiple regression and correlation; multiway analysis of variance, variance components, covariance; elementary principles of design; basic nonparametric methods.
- 5071. STATISTICAL APPLICATION OF MATRIX ALGEBRA.** (3 cr; prereq 5021, ¶Math 3142 or #)  
Specific matrix operations with vector realizations, presuming no prior knowledge. Uses in analysis of variance and multivariate methods. Correlation structures, characteristic vectors, quadratic forms.
- 5101s. INTRODUCTION TO DECISION THEORY.** (4 cr, §5133; prereq Econ 5111 or Math 1142 or 1211 or #)  
Elements of probability; basic concepts in statistical decision theory; relationship to game theory and other types of decision problems; prediction and inference.
- 5121f-5122w. THEORY OF STATISTICS.** (4 cr per qtr, §5131-5132-5133; prereq Math 1231 or 1331 or 1621)  
Univariate and multivariate distributions, law of large numbers, sampling, likelihood methods, estimation and hypothesis testing, regression and analysis of variance and covariance, confidence intervals, distribution-free methods.
- 5131f-5132w-5133s. THEORY OF STATISTICS.** (4 cr per qtr, §5121-5122; prereq ¶Math 3411 or 3211)  
5131: Probability models, univariate and bivariate distributions, independence, basic limit theorems.  
5132-5133: Statistical decision theory, sampling, estimation, testing hypotheses, parametric and nonparametric procedures for one-sample and two-sample problems, regression, analysis of variance. Treatment more mathematical than that in 5121-5122.
- 5201w. SAMPLING METHODOLOGY IN FINITE POPULATIONS.** (4 cr; prereq 5021 or 5121 or 3091 or #)  
Simple random, systematic, stratified, and unequal probability sampling. Ratio and regression estimation. Multistage and cluster sampling.
- 5211. THEORY OF SAMPLE SURVEYS.** (4 cr; prereq 5122 or 5133)  
Mathematical treatment of survey sampling including stratified and multistage sampling, models for nonsampling errors.
- 5271-5272. BAYESIAN DECISION MAKING.** (4 cr per qtr, §Econ 5271-5272; prereq 5133 for 5271, 5271 and Econ 3101 for 5272)  
5271: Axioms for personal probability and utility. Elements of statistical decision theory. Bayesian analysis of linear models. 5272: Expected utility models for economic decisions made under conditions of uncertainty. Applications to portfolio selection, forward and future trading, betting, contingency markets, business planning.
- 5301f,s. DESIGNING EXPERIMENTS.** (4 cr; prereq 5022 or 5122 or 5133 or #)  
Control of variation, construction, and analysis of complete and incomplete block, split plot, factorial, and other groups of similar experiments. Confounding, crossover, and optimum seeking designs.
- 5302f,s. APPLIED REGRESSION ANALYSIS.** (4 cr; prereq 5022 or 5071 or 5122 or #)  
Simple, multiple, and polynomial regression. Estimation, testing, and prediction. Stepwise and other numerical methods; residuals; weighted least squares; nonlinear models; response surface. Experimental research and economic applications.
- 5401s. INTRODUCTION TO MULTIVARIATE METHODS.** (4 cr; prereq 5071, 5022 or 5122 or #)  
Bivariate and multivariate distributions. Inference based on multivariate normal distributions. Discrimination and classification. Multivariate analysis of variance. Partial, canonical correlation and independence. Principal component analysis, factor analysis, analysis of repeated measurements, cluster analysis, profile analysis.

## Course Listings

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- 5421. ANALYSIS OF CATEGORICAL DATA.** (4 cr; prereq 5022 or 5122 or 5133 or #)  
Varieties of categorical data, cross-classifications and contingency tables, tests for independence. Multi-dimensional tables and log linear models, maximum likelihood estimation, and tests of goodness of fit. Analysis of incomplete tables. Marginal homogeneity and symmetry in square tables. Analysis of Markov chain data. Smoothing counts.
- 5601w. NONPARAMETRIC METHODS.** (4 cr; prereq 5022 or 5122 or #)  
Necessary discrete and continuous probability distributions. Goodness of fit, sign tests, order statistics, rank tests for location and for scale, two-sample and k-sample comparisons, association. Methods and applications.
- 5900. TUTORIAL COURSE.** (Cr ar; prereq #)  
Directed study in areas not covered by regular offerings.
- 5911, 5912, 5913. TOPICS IN STATISTICS.** (3 cr per qtr [may be repeated for cr with  $\Delta$ ]; prereq 5122 or 5133. #)  
Topics vary.

### FOR GRADUATE STUDENTS ONLY

(For course descriptions, see the *Graduate School Bulletin*)

- 8151-8152-8153. MATHEMATICAL STATISTICS**
- 8161-8162-8163. APPLIED STATISTICAL METHODS**
- 8171-8172-8173. THEORY OF INFERENCE**
- 8191-8192. LARGE-SAMPLE THEORY**
- 8311-8312. LINEAR MODELS AND EXPERIMENTAL DESIGN**
- 8411-8412. MULTIVARIATE ANALYSIS**
- 8501-8502. INTRODUCTION TO STOCHASTIC PROCESSES WITH APPLICATIONS**
- 8511-8512. TIME SERIES ANALYSIS**
- 8611-8612. NONPARAMETRIC INFERENCE**
- 8731-8732. STATISTICAL DECISION THEORY**
- 8751-8752. SEQUENTIAL ANALYSIS**
- 8801. STATISTICAL CONSULTING**
- 8900. SEMINAR IN STATISTICAL LITERATURE**
- 8931-8932-8933. ADVANCED TOPICS IN STATISTICS**



## V. FACULTY

In the faculty listing that follows, P.E. designates registration as a professional engineer and R.A. designates registration as a registered architect.

### AEROSPACE ENGINEERING AND MECHANICS

#### Professor

Patarasp R. Sethna, *head*  
Gordon S. Beavers, *associate head*  
Abraham S. Berman  
Roger L. Fosdick  
Helmut G. Heinrich  
Philip G. Hodge, Jr.  
Chih Chun Hsiao  
Daniel D. Joseph  
Thomas S. Lundgren  
Robert Plunkett, P.E.  
William H. Warner  
Theodore A. Wilson

#### Associate Professor

William L. Garrard, Jr.  
John P. Moran  
Eugene Stolarik

### AGRICULTURAL ENGINEERING

#### Professor

Arnold M. Flikke, *head*  
Evan R. Allred  
Donald W. Bates  
Harold A. Cloud  
Kenneth A. Jordan  
Curtis L. Larson  
Roger E. Machmeier  
Jesse Pomroy  
Cletus E. Schertz  
John Strait  
John A. True

#### Associate Professor

Frederick G. Bergsrud  
Philip R. Goodrich  
R. Vance Morey  
Ronald T. Schuler  
David R. Thompson

#### Assistant Professor

Robert J. Gustafson  
James A. Moore  
Charles A. Onstad  
Donald C. Stack  
Robert A. Young

### ARCHITECTURE AND LANDSCAPE ARCHITECTURE

#### Professor

Ralph Rapson, R.A. *head*  
Roger D. Clemence  
Carl Graffunder, R.A.  
Thomas H. Hodne, R.A.  
Roger B. Martin  
Valerius Michelson, R.A.  
John S. Myers, R.A.  
Leonard S. Parker, R.A.  
John G. Rauma, R.A.  
James E. Stageberg, R.A.  
Milo H. Thompson, R.A.  
George C. Winterowd, R.A.

#### Associate Professor

David J. Bennett, R.A.  
Joseph Blair, R.A.  
Robert E. Diedrich, P.E., R.A.  
Gunter A. Dittmar  
Dennis W. Grebner, R.A.  
Robert M. Hyseil, R.A.  
Kay M. Lockhart, R.A.  
Richard B. Morrill, R.A.  
Peter Odgaard  
Duane Thorbeck, R.A.

#### Assistant Professor

Gerald E. Allan, R.A.  
Herbert Baldwin, R.L.A.  
John W. Cuningham, R.A.  
Stanley Fishman, R.A.  
Samuel D. Heins, J.D.  
Gerald S. Johnson, R.A.  
Edward Kodet, R.A.  
Lance LaVine, R.A.  
Julia Robinson  
Garth Rockcastle  
David Showalter, R.A.  
John Tietz  
Lee Tollefson, R.A.  
J. Stephen Weeks, R.A.

### ASTRONOMY

#### Regents' Professor

Edward P. Ney

#### Professor

W. Butler Burton, *chairman*  
Wayne A. Stein

#### Associate Professor

Kris Davidson  
Roberta M. Humphreys

#### Assistant Professor

Thomas W. Jones  
Lawrence Rudnick  
J. M. van der Hulst

### CHEMICAL ENGINEERING AND MATERIALS SCIENCE

#### Regents' Professor

Rutherford Aris

#### Professor

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Robert W. Carr, Jr.  
John S. Dahler  
H. Ted Davis  
Arnold G. Fredrickson  
William W. Gerberich  
Herbert S. Isbin  
Morris E. Nicholson, P.E.  
William E. Ranz  
Lanny D. Schmidt  
L. E. Scriven  
Louis E. Toth  
Henry M. Tsuchiya

*Associate Professor*

Christopher W. Macosko  
John M. Sivertsen  
George Stephanopoulos

*Assistant Professor*

Craig L. Jensen  
Matthew V. Tirrell  
John P. Wallace  
Stephen T. Wellinghoff

## CHEMISTRY

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Robert C. Brasted  
Doyle Britton  
Bryce Crawford, Jr.  
John S. Dahler  
H. Ted Davis  
Raymond M. Dodson  
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Robert M. Hexter  
Maurice M. Kreevoy  
Edward Leete  
Sanford Lipsky  
Rufus W. Lumry  
C. Aiden Mead  
Edward J. Meehan  
Larry L. Miller  
Wilmer G. Miller  
Albert J. Moscovitz  
Wayland E. Noland  
John Overend  
Stephen Prager  
Warren L. Reynolds  
Donald G. Truhlar  
John E. Wertz  
Archie S. Wilson

*Associate Professor*

Richard F. Borch  
Robert G. Bryant  
Lawrence E. Conroy  
W. Ronald Gentry  
Jack Z. Gougoutas  
Gary R. Gray  
Louis H. Pignolet

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David Dixon  
John E. Ellis  
John F. Evans  
William E. Farneth  
Jed F. Fisher  
Wayne Gladfelder  
Thomas R. Hoye  
Kent Mann  
Brock Siegel

## CIVIL AND MINERAL ENGINEERING

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Heinz G. Stefan, *associate director of SAFHL*  
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C. Edward Bowers  
Lawrence E. Goodman, P.E.  
Iwao Iwasaki  
Walter J. Maier  
John F. Ripken, P.E.  
Edward Silberman, P.E.  
Anthony M. Starfield  
Donald H. Yardley, P.E.

*Associate Professor*

Ladislav Cerny, *director of CE internship program*  
Steven L. Crouch, *director of graduate studies*  
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Matthew J. Huber, P.E.  
Thomas M. Lillesand  
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*Assistant Professor*

Dimitrios E. Beskos  
Francois Cheong-Siat-Moy  
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Michael R. Hoffman  
Gerald W. Johnson  
Panos G. Michalopoulos  
Christopher St. John  
Eugene L. Skok, Jr.  
Yorgos J. Stephanedes  
Raymond L. Sterling, P.E.  
Otto D. L. Strack

*Instructor*

Karl A. Smith

*Research Associate*

John M. Killen  
George D. Meixel  
Yoshiaki Mizuta  
John R. Santich  
Norman Schulz  
Michael D. Voegelé  
George F. Weaton

*Research Fellow*

Joseph M. Wetzel, *assistant director of SAFHL*  
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Krishna P. Sinha

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Marvin L. Stein

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K.S. Frankowski  
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## EARTH SCIENCES

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Hans O. Pfannkuch  
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William Seyfried  
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## ELECTRICAL ENGINEERING

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William F. Brown, Jr. (emeritus)  
J. Alex Carruthers  
Paul A. Cartwright, P.E.  
Keith S. Champlin  
Lorne M. Chanin  
Robert J. Collins, P.E.  
Richard Y. Kain  
K.S.P. Kumar  
Robert F. Lambert, P.E.  
Rolf K. Mueller  
Allen Nussbaum  
Hendrik J. Oskam  
William T. Peria  
Mahmoud Riaz  
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Belle A. Shenoi  
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Gary Y. Robinson  
Rolf Schaumann  
Alfons Tuszyński  
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Philip I. Cohen  
Mostafa Kaveh

Sivanarayana Mallela  
Narendra Mohan  
Malur K. Sundareshan

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*Professor*

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Laurence R. Harper  
Frederick Howes  
Troels Jorgenson  
Stephan List  
Steven I. Sperber  
John Wierman

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Perry L. Blackshear, Jr.  
Ernst R. Eckert (regents' emeritus)  
Edward A. Fletcher  
Darrell A. Frohrib  
Warren Ibele, P.E.  
Richard C. Jordan, P.E. (emeritus)  
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Benjamin Y. Liu  
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Katsuhiko Ogata  
Emil Pfender  
Ephraim M. Sparrow  
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Arthur G. Erdman, P.E.  
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Virgil A. Marple  
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Charles J. Scott  
Richard D. Springer, P.E.  
Patrick J. Starr

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Peter H. McMurry  
James W. Ramsey  
Donald R. Riley  
Kevin Y. Teichman

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Alfred O. C. Nier

### Professor

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Robert O. Pepin, *director of undergraduate studies*  
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J. Morris Blair  
Laurence J. Cahill, Jr.  
Hans W. J. Courant

Dietrich Dehnhard  
George D. Freier  
Phyllis S. Freier  
Stephen Gasiorowicz  
Donald A. Geffen  
Clayton F. Giese  
Allen M. Goldman  
George W. Greenlees  
J. Woods Halley  
Norton Hintz  
Russell K. Hobbie  
Walter H. Johnson  
Paul J. Kellogg  
Homer T. Mantis  
Jonathan L. Rosner  
Keith Ruddick  
Roger H. Stuewer  
Hiroshi Suura  
Yau Chien Tang  
Cecil J. Waddington  
John R. Winckler  
William Zimmermann, Jr.

### Associate Professor

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Charles Campbell  
Paul Ellis  
Kenneth Erickson (adjunct)  
Roger S. Jones  
Erwin Marquit  
Marvin Marshak  
Konrad Mauersberger  
Earl A. Peterson  
Peter Roll  
Alan Shapiro

### Assistant Professor

Kenneth Heller  
Cheng-Cher Huang  
Oriol T. Valls

## STATISTICS

### Professor

Seymour Geisser, *director*  
Robert J. Buehler  
Raymond O. Collier  
Somesh Das Gupta  
Morris L. Eaton  
Stephen E. Fienberg  
Clifford Hildreth  
David V. Hinkley  
Bernard W. Lindgren  
William D. Sudderth

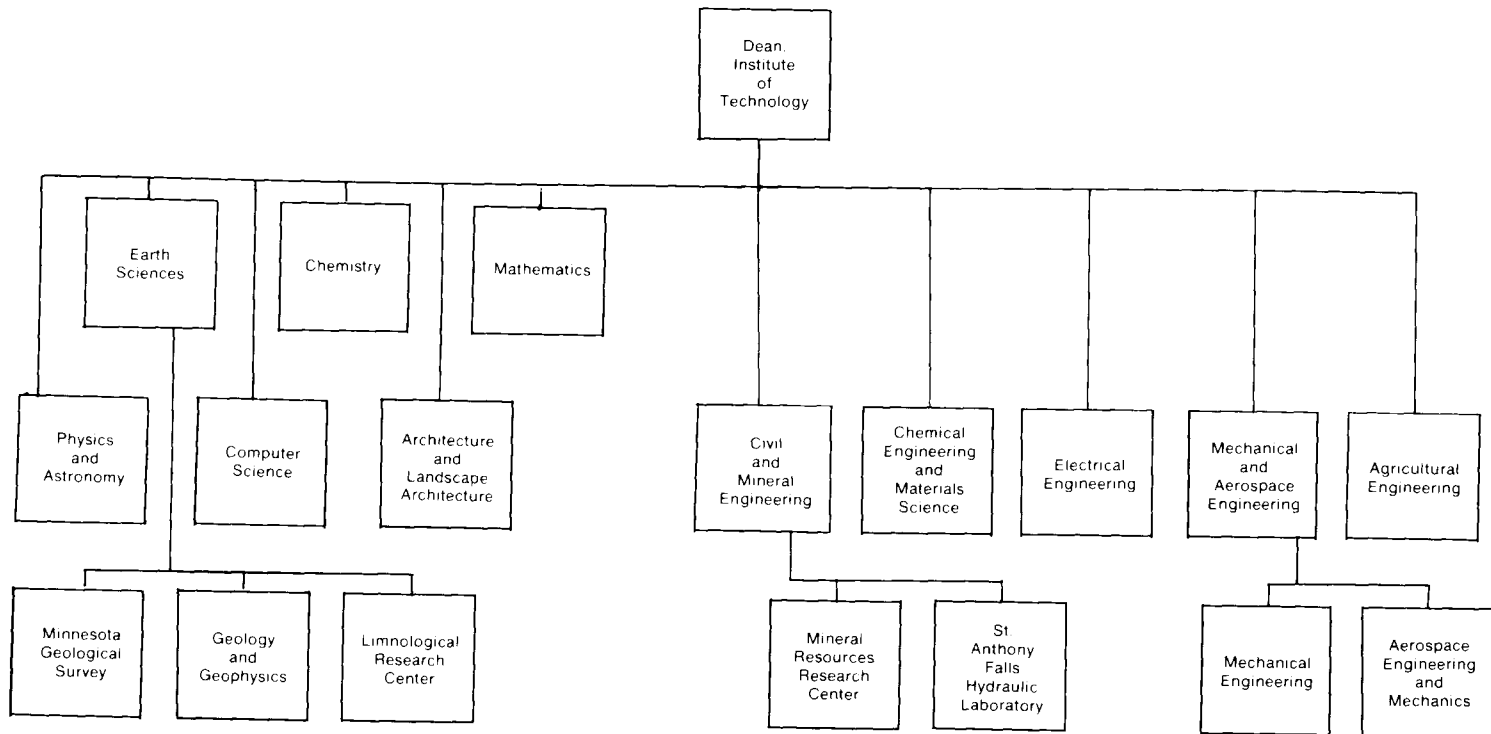
### Associate Professor

Donald A. Berry  
Christopher Bingham  
R. Dennis Cook  
Kinley Larntz  
Frank Martin  
Sanford Weisberg

### Assistant Professor

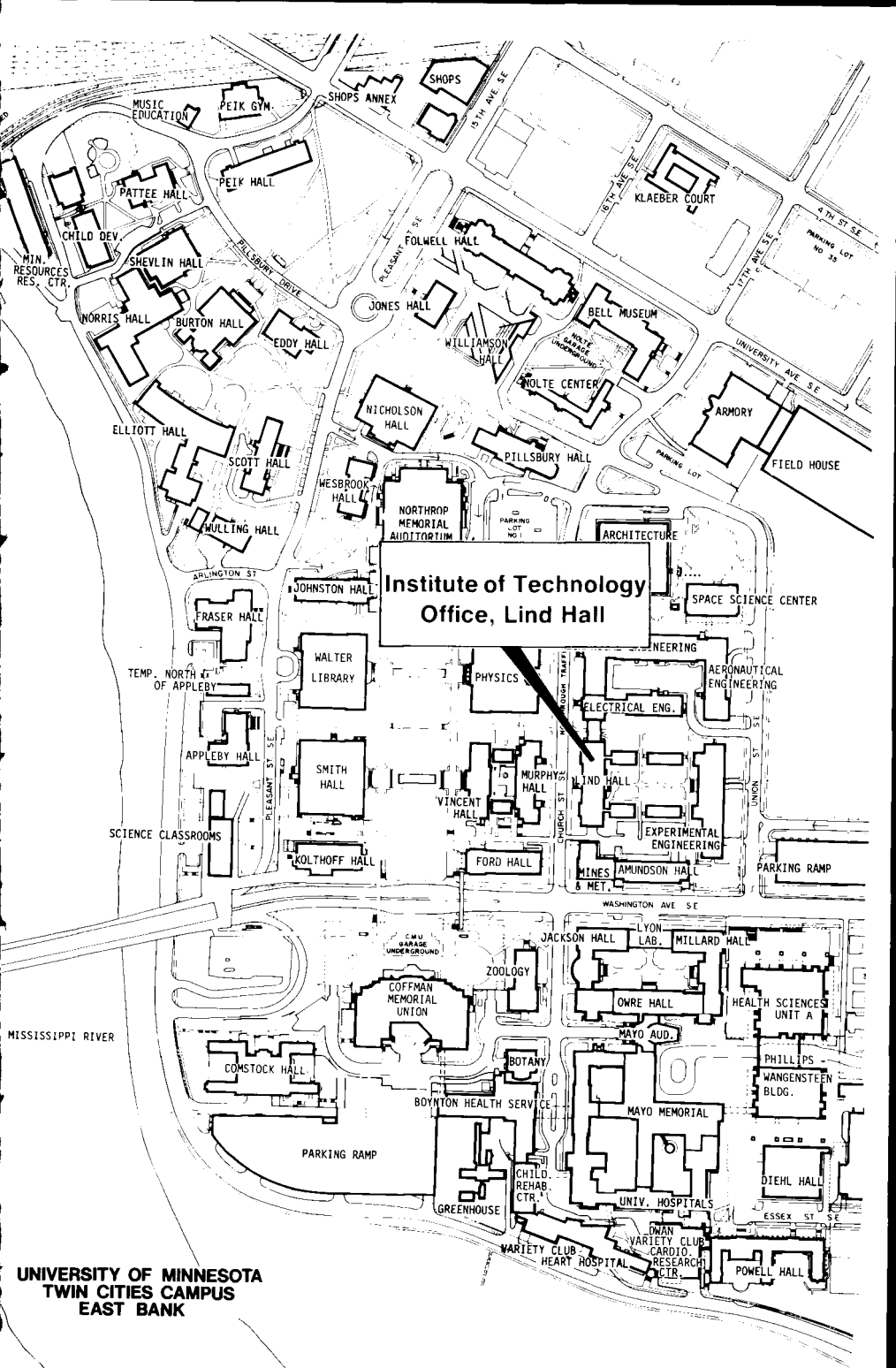
David A. Lane  
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# ORGANIZATIONAL CHART OF THE INSTITUTE OF TECHNOLOGY



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