Institute of Technology

UNIVERSITY OF MINNESOTA

BULLETIN 1995-1997

Institute of Technology

On the cover:

The basis for the cover design is the work of Brent Wolf, a College of Liberal Arts senior in fine arts who works with Institute of Technology students in the Office of Lower Division Programs. Also involved in the design was Eric Engebretsen, a senior in aerospace engineering.

The final cover design was manipulated and arranged in Adobe Photoshop 3.0 and Adobe PageMaker 5.0 by Student Affairs Communications & Publications.

The design represents change over time resulting from technological advancements.

Institute of Technology

Department Offices

(area code 612)

Office of the Dean
105 Walter Library
624-2006

Office of the Associate Dean for Student Affairs
106 Lind Hall
624-5091

Advising Office for Lower Division Programs
128 Lind Hall
624-2890

Student Affairs Office
105 Lind Hall
624-8504

Center for the Development of Technological Leadership
107 Lind Hall
624-5747

IT Honors Office
136 Lind Hall
625-2800

IT Placement Office
50 Lind Hall
624-4090

IT Project Technology Power
339 Walter Library
626-0219

Aerospace Engineering and Mechanics
107 Akerman Hall
625-8000

Agricultural Engineering
213 Agricultural Engineering
St. Paul
625-7733

Astronomy
356 Tate Laboratory of Physics
624-0211

Chemical Engineering and Materials Science
151 Amundson Hall
625-1313

Chemistry
139 Smith Hall
624-6000

Civil and Mineral Engineering
122 Civil and Mineral Engineering
625-5522

Computer Science
4-192 EE/CSci
625-4002

Electrical Engineering
4-174 EE/CSci
625-3300

Geology and Geophysics (Earth Sciences)
108 Pillsbury Hall
624-1333

Mathematics
4 Vincent Hall
625-4848

Mechanical Engineering
125 Mechanical Engineering
625-0705

Physics
148 Tate Laboratory of Physics
624-7375

Statistics
270 Vincent Hall
625-8046

Other Helpful Offices

Office of Admissions
240 Williamson Hall
625-2008

Asian/Pacific American Learning Resource Center
306 Walter Library
624-2317

University Counseling and Consulting Services
109 Eddy Hall
624-3323

Extension Classes Registration
101 Wesbrook Hall
625-3333

Extension Counseling
314 Nolte Center
625-2500

Office of Scholarships and Financial Aid
210 Fraser Hall
624-1665

Housing Services
Comstock Hall—East
624-2994

International Student Adviser's Office
20 Nicholson Hall
626-7100

Student Relations, Transcripts
150 Williamson Hall
625-5333

University Information
625-5000 (off campus)
DIAL 0 (on campus)

Publications

As an Institute of Technology (IT) student, you are responsible for all information in this bulletin that is pertinent to your undergraduate study and to your particular field. In addition, you should be aware of information in the following sources:

Class Schedule—This quarterly publication lists day school courses complete with hours, rooms, instructors, and prerequisites, as well as registration instructions, examination fees, maps, final exam schedules, grading definitions, and other valuable information.

Course Guide—The *Course Guide,* a quarterly publication distributed at the University Bookstores, provides course information in addition to college bulletins and the *Class Schedule.*

Other Bulletins—Evening and summer courses are featured in the *Continuing Education and Extension Classes Bulletin* and *Summer Session Bulletin,* respectively. Bulletins are also published for other University colleges. Most can be obtained at 240 Williamson Hall or by calling (612) 625-2008.

Student Publications—Two publications are produced by students in the Institute of Technology: *IT Connection* (newsletter) and *IT Technolog* (technical magazine). The IT Board of Publications selects editors and business managers and directs the overall policy of the publications. Students are encouraged to participate as staff members of the various publications.

Policies

Bulletin Use—The information in this bulletin and other University bulletins, publications, or announcements is subject to change without notice. University offices can provide current information about possible changes.

This publication is available in alternative formats upon request. Please contact the Office of Admissions, University of Minnesota, 240 Williamson Hall, 231 Pillsbury Drive S.E., Minneapolis, MN 55455 (612/625-2008; e-mail admissions@tc.umn.edu).

This bulletin also is available in electronic format on Internet and may be accessed via Gopher.

Equal Opportunity—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, color, creed, religion, national origin, sex, age, marital status, disability, public assistance status, veteran status, or sexual orientation.

In adhering to this policy, the University abides by the Minnesota Human Rights Act, Minnesota Statute Ch. 363; by the Federal Civil Rights Act, 42 U.S.C. 2000e; by the requirements of Title IX of the Education Amendments of 1972; by Sections 503 and 504 of the Rehabilitation Act of 1973; by the Americans With Disabilities Act of 1990; by Executive Order 11246, as amended; by 38 U.S.C. 2012, the Vietnam Era Veterans Readjustment Assistance Act of 1972, as amended; and by other applicable statutes and regulations relating to equality of opportunity.

Inquiries regarding compliance may be directed to Patricia A. Mullen, Director, Office of Equal Opportunity and Affirmative Action, University of Minnesota, 419 Morrill Hall, 100 Church Street S.E., Minneapolis, MN 55455 (612/624-9547).

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. (Exceptions under the law include state and federal educational and financial aid institutions.) The

policy also permits students to review their educational records and to challenge the contents of those records.

Some student information—name, address, electronic (e-mail) address, telephone number, dates of enrollment and enrollment status (full time, part time, not enrolled, withdrawn and date of withdrawal), college and class, major, adviser, academic awards and honors received, and degrees earned—is considered public or directory information. Students may prevent the release of public information only during their terms of enrollment. To do so, they must notify the records office on their campus.

Students have the right to review their educational records. The regents' policy, including a directory of student records, is available for review at 150 Williamson Hall, Minneapolis, and at records offices on other campuses of the University. Questions may be directed to the Office of the Registrar, 150 Williamson Hall (612/625-5333).

Immunization—Students born after 1956 who take more than one University class are required under Minnesota law to submit an Immunization Record form.

The form, which is sent along with the official University admission letter, must be filled out and returned to Boynton Health Service within 45 days of the first term of enrollment in order for students to continue registering for classes at the University. Complete instructions accompany the form.

Extracurricular Events—No extracurricular events requiring student participation may be scheduled from the beginning of study day to the end of finals week. Exceptions to this policy may be granted by the Senate Committee on Educational Policy. The Senate advises all faculty that any exemption granted pursuant to this policy shall be honored and that students who are unable to complete course requirements during finals week shall be provided an alternative and timely opportunity to do so.

Smoke-Free Campus Policy—Smoking is prohibited in all facilities of the University of Minnesota, Twin Cities campus except for designated private residence hall rooms.

Programs and Services

For more than a century, the Institute of Technology (IT) has provided education, research, and technology transfer in science and engineering. With 4,500 students enrolled in its undergraduate programs, 2,000 in graduate programs, and 400 faculty, IT's 11 departments and schools and 15 research centers are committed to excellence in all that they undertake.

Degrees Offered

Undergraduate Degrees—Each of IT's undergraduate programs provides a rigorous and stimulating education that is enhanced by close interaction with distinguished research faculty and access to IT's research facilities.

Sixteen degrees are offered:

bachelor of aerospace engineering and mechanics[1]
bachelor of science in astrophysics
bachelor of biosystems and agricultural engineering[1]
bachelor of chemical engineering[1]
bachelor of science in chemistry
bachelor of civil engineering[1]
bachelor of science in computer science
bachelor of electrical engineering[1]
bachelor of geological engineering[1]
bachelor of science in geology
bachelor of science in geophysics
bachelor of materials science and engineering[1]
bachelor of science in mathematics
bachelor of mechanical engineering[1]
bachelor of science in physics
bachelor of science in statistics

Graduate Degrees—The University of Minnesota is the only institution in the state that offers a full range of graduate programs in mathematics and computer science, the physical sciences, and engineering. Each IT department offers M.S. and Ph.D. degree programs in several areas within its discipline. For detailed information about the various graduate programs, consult the *Graduate School Bulletin.*

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.

[1] *Program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).*

The management of technology program is an innovative graduate program for technical professionals who are ready to assume management positions. It is a part-time, two-year program leading to the degree of master of science in the management of technology (MS-MOT). For more information, please contact the Center for the Development of Technological Leadership, 107 Lind Hall, 207 Church Street S.E., Minneapolis, MN 55455 (612/624-5747).

Special Programs

Interdisciplinary Programs—IT students can plan interdisciplinary programs tailored to their specific interests. Although a degree is conferred by a single department, students can combine coursework from several departments.

Many interdisciplinary programs are possible. A few examples include acoustics, bioengineering, environmental engineering, nuclear engineering, and transportation. Students should contact their department office or visit 105 Lind Hall for more information.

Honors Program—The IT honors program provides special educational experiences to those students who have the ability and motivation to accept an extra challenge. Honors opportunities include a specially designed academic curriculum during the freshman and sophomore years, upper division programs leading to the *cum laude* degrees, close contact with instructors, opportunities for research, and a variety of elective honors courses, seminars, and colloquia offered in IT and the College of Liberal Arts.

During the freshman year, most lower division honors students take enriched mathematics, physics, and chemistry courses that provide excellent preparation for any IT major. Students also participate in the many social and other cocurricular activities initiated by the IT Student Honors Group.

This special lower division academic program continues into the sophomore year offering enough flexibility so students can take the courses they need to pursue any major. For the junior and senior years, each department offers its own upper division honors program consisting of courses, research projects, and honors opportunities leading to the *cum laude* degrees.

Admission to the Lower Division Program—Most lower division honors students begin their participation in the honors program in the fall of the freshman year. These students apply and are admitted in their senior year of high school. Selection is based on academic accomplishments in high school, scores on standardized tests, an application essay, and a recommendation usually from a teacher or counselor. The priority application deadline for freshman admission is January 15. Applications may be obtained by contacting the IT Honors Office, 136 Lind Hall (612/625-2800) or the Office of Admissions, 240 Williamson Hall (612/625-2008).

Students with excellent grades in regular courses during the fall of their freshman year may apply to enter the honors program for winter quarter. These students should have taken the appropriate first-quarter mathematics and physics courses so they are prepared for the corresponding honors sequences.

Admission to Upper Division Programs—Students about to enter their junior year may apply to the upper division honors program administered through their major department. Admission requirements are set by the individual departments and may be obtained from the department or the IT Honors Office. Previous enrollment in the lower division honors program is *not* required for participation in upper division honors programs.

Graduation with Honors—Enrollment in the upper division honors program is required for graduation with the honors designations *cum laude, magna cum laude,* and *summa cum laude.* Other graduation criteria include University of Minnesota residence (see page 20), quality of the grade record, participation in honors opportunities, fulfillment of requirements designated in the major field, and, for *summa cum laude,* an honors thesis. Some departments also require theses for *cum laude* and *magna cum laude* degrees.

IT Honors Office—This office provides academic advising, procedural information, and other college office services to honors students. The address is University of Minnesota, 136 Lind Hall, 207 Church Street S.E., Minneapolis, MN 55455 (612/625-2800).

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 two years of study. Students should contact their department 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 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 1009 plus 5 cr in biology, zoology, or genetics (10 cr)
- Chem 1051-1052, 3100, 3101, 3301, 3302, 5126 (25 cr)
- Comp 1011 and literature (12 cr)
- Math 1251-1252—mathematics through calculus (8 cr)
- Phys 1104-1105-1106-1107-1108-1109, or 1251-1252-1253 (12-15 cr)
- At least 27 cr, evaluated on A-F grading, in humanities, social science, foreign language, or other liberal arts areas (literature and humanities recommended)

Students considering careers 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.

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 on application procedures, students should consult the premedical adviser in their IT department.

Project Technology Power (PTP)—This program identifies and removes barriers that discourage Africans, African Americans, Native Americans, and Chicanos/Latinos from

pursuing careers in computer science, engineering, or science by providing technical, academic, and other support programs to pre-college and college-level student. At the pre-college level, PTP sponsors academic enrichment programs for eighth- through tenth-grade students in Minneapolis and St. Paul. IT students, teachers, and industry representatives facilitate the programs. At the college level, PTP offers academic and career counseling, merit scholarships, tutoring, practice interviews, résumé writing, and assistance in obtaining summer or permanent technical work experience.

Reserve Officers Training Corps—Qualified 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 two-, three-, and four-year programs. Participating students, upon completion of the program, receive a commission as an officer in their respective service. ROTC curricula are designed to provide instruction and practice in leadership and management skills as well as military and related subjects. Of important note is the various financial aid available, ranging from tax-free monthly allowances to four-, three-, and two-year scholarships. A scholarship ($1,000 of which is tax-free each year) pays all tuition and provides an allowance for books, supplies, and fees. Present service requirements give IT students first priority. Interested students should consult the *Army-Navy-Air Force ROTC Bulletin* or inquire at the following offices in the Armory on the Minneapolis campus: Military Science, Room 108, 612/624-7300 (collect); Naval Science, Room 203, 612/625-6677; and Aerospace Studies, Room 3, 612/624-2884.

Study Abroad—IT students have a number of opportunities for study abroad. Study in English is possible at several sites. Opportunities include ISEP (International Student Exchange Program) and IAESTE (International Association for the Exchange of Students for Technical Experience).

Identifying Study Abroad Opportunities—The *Study Abroad Catalog* describes the broad range of opportunities for University of Minnesota students to study in another country as part of their degree program. Students can learn more about these options through an advising appointment at the International Study and Travel Center (ISTC), 102 Nicholson Hall (612/625-1150).

Study Abroad Opportunities in Engineering—The University's student exchanges and consortium memberships give students access to engineering courses at universities in many countries. Courses taught in English are available in Australia, Canada, Finland, Malta, Singapore, Sweden, Tanzania, and the United Kingdom. Students with sufficient language fluency may instead choose to study in Chinese (Hong Kong), Filipino (Philippines), Finnish (Finland), French (Belgium, France), German (Germany), Italian (Italy), Korean (South Korea), Portuguese (Brazil), Spanish (Argentina, Colombia, Costa Rica, Dominican Republic, Mexico), or Thai (Thailand). The range of opportunities is even greater for math or science majors.

Other Study Abroad Opportunities—Science and engineering students need not necessarily seek credit in their major. Study abroad is encouraged for language acquisition, cultural learning, or practical field experience. The resulting credits can often be used as electives. A broad range of intensive short-term language programs, area studies programs (which offer courses on the culture, society, and language of the host country), and field study programs (which include group programs, individual research programs, and internships) are available. These programs are sponsored by the University or other institutions. Contact ISTC for more information.

Credit for Study Abroad—Advance planning and IT endorsement are essential to ensure that credit from study abroad fits smoothly into the student's degree program. A student who enrolls in a University of Minnesota program will receive procedural information from the sponsoring office on

campus. Those who select any other option should make an advising appointment at the Foreign Studies Program office (104 Nicholson Hall, 612/624-4525) to discuss credit procedures and obtain a *Foreign Study Checklist.* Through the *Checklist,* appropriate IT faculty or advisers will record their instructions and agreements concerning credit. The Checklist also helps maintain the student's enrollment status and financial aid eligibility while abroad.

Financial Aid—For nearly all study programs students can arrange to retain their eligibility to receive financial aid through the University and defer past loans. Additional financial aid is available for some programs. Contact ISTC for more information.

Program for Women—IT's Program for Women supports women in their pursuit of science and engineering education and careers. Services are provided to women undergraduate and graduate students, transfer and nontraditional students, faculty, technical staff, fellows, and pre-college girls.

The program recruits talented women in an attempt to increase the enrollment of women in IT degree programs to levels above national trends. It builds networks for IT women, provides skills and tools for success, and works to improve the climate for women in individual departments. Its outreach efforts focus on encouraging girls to explore and enjoy mathematics and science as well as educating parents, teachers, leaders, and the greater community on their critical roles in supporting girls and women in science and engineering. The program also provides student referral, scholarship and fellowship files, a resource library, networking information, MN-WISE electronic list server, and advocacy.

Computer Facilities

The Institute of Technology, in cooperation with Computer and Information Services, has established a number of computer laboratories for students. These laboratories allow interactive computing, using either stand-alone computers and workstations or remote access to central computing facilities, including those of the Minnesota Supercomputer Center. Laboratories are available to IT students at any time during the working day and during some evening and weekend hours.

Students also have access through their departments to many special-purpose machines, ranging from small tabletop units for data reduction in laboratories to larger models reserved for special projects.

The Department of Computer Science offers a series of courses in FORTRAN, C, and C++. Discipline-related computing courses are offered in some departments.

In addition, full-time students, faculty, and staff can purchase microcomputers, software, and peripheral equipment at a significant discount through the University. Information on the microcomputer discount program is available at Computer and Information Services, 125 Shepherd Labs.

The University Libraries' card catalog, catalogs at many other institutions, and many databases are available through the campus computer network.

Electronic mail accounts are established for all students.

Admission

Prospective Student Advising—If you wish to discuss your individual situation, you may arrange an interview with an admissions counselor in the Office of Admissions, 240 Williamson Hall, 231 Pillsbury Drive S.E., Minneapolis, MN 55455-0213 (612/625-2008). When you come for an interview, please bring transcripts of high school and/or college work, test results, and any other information pertinent to the interview. To schedule a campus visit with a tour, call the Office of Admissions VISITLINE (612/625-0000).

Freshman Admission

The Office of Admissions reviews all applications to determine applicants' potential for academic success. This review process falls into two categories: automatic admission or admission by individual review in which freshman applicants whose records do not meet automatic admission requirements are evaluated through the Office of Admissions' individual

review process. If you do not meet criteria for automatic admission, you should still apply.

Criteria for Automatic Admission—You will be automatically admitted to IT as a freshman if you:

1. Submit your complete application, including all test scores and transcripts, with a $25 application fee before the freshman class fills (ACT preferred, SAT accepted; applying early in your senior year in high school strongly recommended)
2. Complete the following high school course preparation requirements:
   - Four years of English—with emphasis on writing, including instruction in reading and speaking skills and in literary understanding and interpretation. (If you are not a native speaker of English *and* 1) you have an ACT English score of 17 or lower or 2) took English as a second language in high school, then you will have to submit scores from the Michigan English Language Battery [MELAB]. Call the Office of Admissions for details.)
   - Four years of mathematics—including elementary algebra, geometry in two and three dimensions, intermediate algebra, and trigonometry
   - Three years of science—including one year each of biological science, chemistry, and physics
   - Two years of a single second language
   - Two years of social studies—including U.S. history
3. Admission decisions are based on grades in high school English, mathematics, and science and on the aptitude rating (AAR) calculated as follows:

   AAR = High school rank percentile + 2 times the ACT (American College Test program) composite standard score.
   SAR = High school rank percentile + 0.1 times the SAT (Scholastic Aptitude Test) verbal score + 0.1 times the SAT mathematics score.

   An AAR of 130 or better, or SAR of 185 or better, guarantees admission. If your AAR or SAR are below the automatic admission cutoffs, your application will qualify for the Office of Admissions' individual review process.

Admission by Individual Review—Review considerations may be based on one or more of the following:

1. A pattern of steady improvement in academic performance
2. A strong college preparatory curriculum (including advanced placement) or a particularly challenging pattern of coursework
3. The size of the applicant's high school graduating class
4. Extenuating circumstances that have adversely affected the applicant's academic record or test scores
5. Evidence of exceptional achievement or aptitude not reflected in the applicant's academic record or pre-admission test scores
6. Evidence of exceptional talent or ability in artistic, scholarly, leadership, or athletic performance

Evaluation of College Coursework—No college coursework is required for freshman admission. However, applicants who have completed any transferable college work should have a grade point average (GPA) of at least 2.70 in transferable credits (in addition to meeting criteria 1-3 above) to qualify for automatic admission. Applications of students with GPAs of less than 2.70 will be individually reviewed.

Admission to Other University of Minnesota, Twin Cities Colleges—Applicants who are not admitted to IT may be considered for admission to a freshman-admitting college that matches their needs, backgrounds, interests, and abilities. The other freshman-admitting colleges on the Twin Cities campus are the Colleges of Liberal Arts; Agricultural, Food, and Environmental Sciences; Human Ecology; Natural Resources, and General College. Students who satisfactorily complete prerequisite work in one of these colleges may apply for admission to IT at a later time. For admission requirements of other colleges, see the appropriate college bulletins.

Appeals—Any student who believes that the circumstances concerning their application need further consideration may submit a written appeal to the Office of Admissions.

Residence—Because the University is a state institution, Minnesota residents pay lower tuition than nonresidents and, in many programs, receive priority consideration for admission. To qualify for resident status, students must reside in Minnesota for at least one calendar year before the first day of class attendance. For more information, contact the Resident Classification and Reciprocity Office, 240 Williamson Hall, 231 Pillsbury Drive S.E., Minneapolis, MN 55455 (612/625-6330), or the residency office on your campus.

Reciprocity—The University has reciprocity agreements with North Dakota, South Dakota, Wisconsin, and Manitoba. The University also participates in a reciprocity program with Kansas, Michigan, Missouri, and Nebraska, for students in the following undergraduate colleges: Agricultural, Food, and Environmental Sciences; Architecture and Landscape Architecture; Biological Sciences; Education and Human Development; Human Ecology; Natural Resources; Carlson School of Management, Pharmacy; Dental Hygiene; School of Nursing, and Institute of Technology. If you are a resident of any of these states or this province, you may qualify for reciprocity tuition rates, which are lower than nonresident tuition rates and, in some cases, comparable to resident rates. For more information, contact the Resident Classification and Reciprocity Office, 240 Williamson Hall, 231 Pillsbury Drive S.E., Minneapolis, MN 55455 (612/625-6330), or the residency office on your campus.

Nonresident Admission—Nonresidents, including international students and applicants from states *other than* Minnesota, Wisconsin, North Dakota, and South Dakota or the province of Manitoba, are admitted for fall quarter only. All admission decisions are based on academic records. Advanced standing admission is also based on the availability of space in the program to which admission is sought.

Tuition Deposit—Admitted freshmen must submit a nonrefundable $50 tuition deposit, to be applied to first quarter's tuition. The tuition deposit deadlines are May 1 for fall quarter and November 1 for winter quarter. As an admitted freshman, you must pay the deposit by the deadline or within two weeks after the date on your admission notification letter (whichever is later). If you do not submit the deposit by the deadline, the admission will be rescinded.

Beginning at Other University Colleges—Freshmen may begin in any college at the Twin Cities, Morris, or Duluth campuses. Transfer into the upper division of the Institute of Technology is automatic provided the first two years of coursework were completed at the University and the same grade point was achieved as that required of students beginning in the Institute of Technology. An Application for Change of Status or College is used to change campus and to apply for the upper division. (See Upper Division under Scholastic Policies.) This program is open to qualified resident and nonresident applicants.

Early Admission—Outstanding high school students who have not yet graduated may be admitted to the University, but must be sufficiently mature to adjust to University life and work. Personal interviews, comprehensive testing, and letters of recommendation from high school officials and parents are required. *High School Specials* are students who enroll for courses while completing high school work. For an admission application, contact the Office of Advanced High School Student Services, 107 Armory, 15 Church Street S.E., Minneapolis, MN 55455 (612/626-1666). *Early Admits* are outstanding students who have not completed high school yet enter the University as full-time degree-seeking students; normally, they do not receive a high school diploma.

Upper Division Admission—Students entering as freshmen or sophomores must apply for admission to the upper division (junior and senior years). New freshmen and sophomores are told upon admission and at orientation what GPA might be required for entry into their desired upper division major field. (See Upper Division under Scholastic Policies for procedure.)

Admission Without a Designated Major—Students who want to keep their options open and learn about IT fields before selecting a specific major should indicate "IT Undecided" on the application for admission. They receive advising

from the Office of Lower Division Programs until they are admitted to upper division. During that period students are given the opportunity to use the many resources available in that department to learn about IT fields. Some of the services include mentors; peer, faculty, industry, and alumni advisers; special courses; and written materials. These special programs provide information about career opportunities in IT's various fields and other colleges and help students avoid the mistake of selecting a major for the wrong reasons.

All students are urged to take advantage of the very beneficial Industry Adviser and Mentor Programs, through which they can visit selected industries to talk and learn about engineering and science fields with an engineer and/or scientist of their choice. Currently, more than 200 engineers and scientists from Honeywell, 3M, and NSP serve as advisers to IT students through this program. Arrangements to participate are made in 128 Lind Hall.

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

Advanced Placement is sponsored by the College Entrance Examination Board in certain high schools. Awards for the Institute of Technology are:

Area/Test	Score	Award[1]
Art History	3,4,5	4 cr ArtH 1002 (Introduction to the History of Art)
Biology	3,4,5	5 cr Biol 1201 (Evolutionary and Ecological Perspectives) and 5 cr Biol 1009 (General Biology); counts toward biological science/lab requirement
Chemistry	3,4,5	8 cr Chem 1051, 1052 (General Principles of Chemistry); counts toward physical science/lab requirement
Classics/Latin		
Catullus, Horace	3,4,5	5 cr Lat 3105 (Latin Readings: Catullus and Ovid)
Virgil	3,4,5	5 cr Lat 3106 (Latin Readings: Virgil)
Computer Science		
A	3,4,5	4 cr CSci 3001 (Perspectives on Computers in Society)
AB	4,5	4 cr CSci 3102 (Introduction to Programming)
Economics		
Micro	3,4,5	4 cr Econ 1101 (Principles of Microeconomics); counts toward social science requirement
Macro	3,4,5	5 cr Econ 1102 (Principles of Macroeconomics); counts toward social science requirement
English		
Language/Comp	3,4,5	5 cr Comp 1011
Lit/Comp	3,4,5	5 cr Comp 1011; 4 cr Engl 1999; counts toward literature requirement
French Literature	3,4,5	5 cr Fren 3099 [2]; counts toward the literature requirement
Gov't and Politics		
American	3,4,5	5 cr Pol 1001; counts toward social science requirement
Comparative	3,4,5	4 cr Pol 1054; counts toward social science requirement and international perspectives requirement
History		
American	3,4,5	8 cr Hist 1999 [2]; counts toward historical perspectives and cultural diversity requirements
European	3,4,5	8 cr Hist 1999 [2]; counts toward historical perspectives and international perspectives requirements
Math		
Calculus AB	3,4	4 cr Math 1251 (Calculus I); counts toward mathematical thinking requirement
	5	8 cr Math 1251, 1252 (Calculus I-II); mathematical thinking
Calculus BC	3	4 cr Math 1251 (Calculus I); mathematical thinking
	4	8 cr Math 1251, 1252 (Calculus I-II); mathematical thinking
	5	12 cr Math 1251, 1252, 1261 (Calculus I-II-III); mathematical thinking
Music		
Music Theory	3,4,5	4 cr Mus 1001 (Fundamentals of Music)
Music Listening and Literature	3,4,5	4 cr Mus 1021 (Introduction to Music); counts toward visual and performing arts requirement and international perspectives requirement
Physics		
B	3,4,5	(CLA and architecture) 5 cr Phys 1041 and 5 cr 1042 (Introductory Physics); counts toward physical science/lab requirement
C	3,4,5	8 cr Phys 1251, 1252 (General Physics); counts toward physical science/lab requirement
Psychology	3,4,5	5 cr Psy 1001; counts toward social sciences requirement
Spanish Literature	3,4,5	5 cr Span 3099 [2]; counts toward literature requirement

[1] *Students will be granted course credit plus credits toward fulfillment of the University's liberal education requirements for graduation.*

[2] *Course numbers 1999 and 3099 indicate blanket credit in the subject matter area at the freshman-sophomore and junior-senior levels respectively; other numbers are those of specific courses for which students may be granted credit. Note: Students may be awarded credit in a second language by taking a proficiency examination. Call (612) 624-6811. Art students may present a portfolio to the Department of Art. Call (612) 625-8096.*

International Baccalaureate (IB) awards, available in a number of secondary schools in Canada and the United States, are made as follows:

Higher-level subject	Grade	Credit award
Art/Design	5-7	4 cr ArtS 1401 8 cr ArtS 1999
Biology	5-7	5 cr Biol 1201 5 cr Biol 1009 2 cr Biol 1999
Chemistry	5-7	4 cr Chem 1051 4 cr Chem 1052 4 cr Chem 1999
Economics	5-7	4 cr Econ 1101 4 cr Econ 1102 4 cr Econ 1999
English A	5-7	7 cr Engl 1999 (lit) 5 cr Comp 1011
History *(American or European)*	5-7	12 cr Hist 1999
Math	5-7	4 cr Math 1251 4 cr Math 1252 4 cr Math 1261
Physics	5-7	4 cr Phys 1251 4 cr Phys 1252 4 cr Phys 1253
Other subjects	5-7	12 cr subject (under review, please inquire)

Advanced Standing Admission

Students who have completed a year or more of college work (39 or more quarter credits) are considered for admission with advanced standing. Students planning to transfer to IT should be pursuing a lower division engineering, science, or math program. The mathematics, chemistry, physics, and computer science courses required for the preferred major should be mostly completed at the time of application. Admission decisions are based on the overall GPA and grades in science and mathematics. Since demand for some IT programs exceeds available places, applicants are asked to indicate three majors in order of preference. Applications must include recent transcripts from *all* colleges attended, reflecting all college work attempted (whether satisfactorily completed or not). Applications for fall 1993 and thereafter must also include a high school transcript to show whether the preparation requirements listed on page 10 have been met.

Resident applicants (students from Minnesota, the reciprocity states, and the province of Manitoba) must apply by April 1 for fall quarter, October 15 for winter quarter, and January 15 for spring quarter.

Nonresidents, as defined on page 11, are admitted on a selective basis for the fall quarter only.

Most courses transfer routinely. Equivalency for technical courses has been established between IT and Upper Midwest colleges and universities. Technical courses in which a grade of D has been earned do not transfer, unless the following course in the sequence was completed with a grade of C or better.

Dual Degree (3/2) Programs—The Institute of Technology has arranged cooperative agreements with a number of selected public and private colleges. These programs support those who want to combine a strong liberal arts background with study in engineering—and who are willing to spend another year or two achieving this goal.

Under one plan a student can complete three years of study at a private college and then transfer to IT for two additional years. At the private college, core college requirements and the pre-engineering core courses in math and science are completed. A bachelor's degree will be awarded by both the private college and the Institute of Technology.

The second plan requires completion of a bachelor of arts degree in math or science before coming to the University to work toward a master of science degree in engineering. This typically involves completing some undergraduate engineering coursework. This plan minimizes the amount of undergraduate coursework required. The amount of such coursework will vary by department and area of study. Participating colleges include: (in Minnesota) Augsburg College, Bethel College, Gustavus Adolphus College, Hamline University, Macalester College, Moorhead State University, Northwestern College, the College of St. Catherine, St. John's University-College of St. Benedict, University of St. Thomas; (outside Minnesota) Augustana College, SD; Jackson State University, MS; Luther College, IA; North Central College, IL; North Park College, IL; Whittier College, CA.

Planning to Transfer?

Minnesota's public colleges and universities are working to make transfer easier. You can help if you PLAN AHEAD, ASK QUESTIONS, and USE PATHWAYS created by transfer agreements.

Preparing for Transfer

If you are currently enrolled in a college or university:

- Discuss your plans with the campus transfer specialist in the Student Affairs Office, 105 Lind Hall.
- Call or visit your intended transfer college. You should obtain the following materials and information:
  — college catalog
  — transfer brochure
  — information on admissions criteria and on materials required for admission (e.g., portfolio, transcripts, test scores). Note that some majors have limited enrollments or their own special requirements such as a higher GPA.
  — information on financial aid (how to apply and by what date)
- After you have reviewed these materials, make an appointment to talk with an adviser/counselor in the college or program you want to enter. Be sure to ask about course transfer and admission criteria.

If you are not currently enrolled in a college or university, you might begin by meeting with a transfer specialist or an admission officer at your intended transfer college to plan the steps you need to take.

Understanding How Transfer of Credit Works

- The receiving college or university decides what credits transfer and whether those credits meet its degree requirements. The accreditation of both your sending and your receiving institution can affect the transfer of the credits you earn.
- Institutions accept credits from courses and programs like those they offer. They look for similarity in course goals, content, and level. "Like" transfers to "like."
- Not everything that transfers will help you graduate. Baccalaureate degree programs usually count credits in three categories: general education, major/minor courses and prerequisites, and electives. The key question is, "Will your credits fulfill requirements of the degree or program you choose?"
- If you change your career goal or major, you might not be able to complete all degree requirements within the usual number of graduation credits.

Applying for Transfer Admission

- Application for admission is always the first step in transferring. Fill out the application as early as you can prior to the deadline. Enclose the application fee.
- Request that official transcripts be sent from every institution you have attended. You might be required to provide a high school transcript or GED test scores as well.
- Recheck to be certain you supplied the college or university with all the necessary paperwork. Most colleges make no decisions until all required documents are in your file.
- If you have heard nothing from your intended college of transfer after one month, call to check on the status of your application.
- After the college notifies you that you have been accepted for admission, your transcripted credits will be evaluated for transfer. A written evaluation should tell you which courses transfer and which do not. How your courses specifically meet degree requirements may not be decided until you arrive for orientation or have chosen a major.
- If you have questions about your evaluation, call the Office of Admissions and ask to speak with a credit evaluator. Ask why judgments were made about specific courses. Many concerns can be cleared up if you understand why decisions were made. If not satisfied, you can appeal. See "Your Rights as a Transfer Student" below.

Your Rights as a Transfer Student

- A clear, understandable statement of an institution's transfer policy.
- A fair credit review and an explanation of why credits were or were not accepted.
- A copy of the formal appeals process.

  Usual appeals steps are: 1) Student fills out an appeals form. Supplemental information you provide to reviewers—a syllabus, course description, or reading list—can help. 2) Department or committee will review. 3) Student receives, in writing, the outcome of the appeal. 4) Student can appeal decision to Ben Sharpe, 105 Lind Hall.
- At your request, a review of your eligibility for financial aid or scholarships.

For help with your transfer questions or problems, see your campus transfer specialist.

Adult Special Admission—Persons interested in completing individual courses or groups of courses to meet their own needs, rather than to pursue degree programs, may be admitted as adult special students. Applicants must usually have a bachelor's degree and meet criteria similar to that required of advanced standing students. Although adult special students are not considered degree candidates, they may subsequently begin degree work when recommended by the departments 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.

International Student Admission—Students wishing to apply to IT who are or will be on a student visa are admitted for the fall quarter only. Applications must be submitted by *April 1*. Selection is based on the student's academic record and the availability of space. Applications for fall 1993 and thereafter must include secondary school transcripts in addition to any university-level records. Freshman applicants must meet the course preparation requirements described on page 11.

English Proficiency—If English is not your native language, you may be required to take the Test of English as a Foreign Language (TOEFL) or the Michigan English Language Assessment Battery (MELAB). To register for the TOEFL, contact the agency that handles TOEFL registration in your country or write to the Educational Testing Service (Box 899, Princeton, NJ 08540 USA) at least 10 weeks before any scheduled test date. If you are already in the Twin Cities area, you may register for the MELAB with the Minnesota English Center, 320 16th Ave. S.E., University of Minnesota, Minneapolis, MN 55455, or call (612) 624-1503. To register for the MELAB outside the Twin Cities area, contact the English Language Institute, Testing and Certification Division, University of Michigan, Ann Arbor, MI 48109 USA, or call (313) 764-2416.

Summer Session—Qualified students, including those from high school, may register for University courses offered in the summer. Students need not apply, but may register as "summer only" students. Information on summer offerings is available from the Summer Session Office, 135 Johnston Hall, 101 Pleasant Street S.E., Minneapolis, MN 55455 (612/624-3555).

Housing—If you're looking for a place to live, either on or off-campus, University Housing Services can help you. *Living In*, a booklet describing on-campus residence facilities and containing an application for campus residence halls, is available in January. To add your name to the mailing list for this application booklet, you should call, write, or visit Housing Services by the end of January.

Housing Services is located in Comstock Hall-East, 210 Delaware Street S.E., University of Minnesota, Minneapolis, MN 55455 (612/624-2994).

Financial Aid

The University offers three general types of financial aid to undergraduates: scholarships and grants, student loans, and college work-study. A student employment service to help students find jobs is also available. For more information, contact the Office of Scholarships and Financial Aid, University of Minnesota, 210 Fraser Hall, 106 Pleasant Street S.E., Minneapolis, MN 55455 (612/624-1665).

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.

Entering freshmen are eligible to apply for the Undergraduate Assistant Scholarship Program, which entails a $2,000 award and involvement with a faculty member on a research project. The program gives students exposure to the research effort of their particular department and brings them into close contact with outstanding professors. Students must apply before January 15 of their senior year in high school. More information is available by calling (612) 625-2800.

International students do not qualify for financial aid.

Student Services

Student Affairs Office—Prospective and current students can discuss any questions or problems with a member of the advising staff in the student affairs office, 105 Lind Hall (612/624-8504). This office is administratively responsible for admission, orientation, registration, scholastic conduct, institute-wide scholarships, degree requirements and procedures, and related functions. Appointments are encouraged.

University Counseling and Consulting Services—University Counseling and Consulting Services (UCCS) offers counseling for academic, career, personal, or relationship concerns. Besides counseling, UCCS features a variety of services. The Career Development Center and the Learning and Academic Skills Center offer workshops, courses, and materials for career development or academic skills improvement. The Organizational Development Program offers consultation, assessment, team building, conflict mediation, training, and workshops. UCCS's Measurement Services office administers tests; scores exams, surveys, and research instruments for University faculty; and operates the Minnesota Statewide Testing Program for Minnesota elementary and secondary schools. The Testing Center administers admissions, placement, and national tests.

Academic Advising

Academic advising is a crucial component of the University's educational mission. Although the approach to advising varies among the different colleges and departments, these general principles apply:

- Academic advising is available to prospective and currently enrolled students.
- Academic advising addresses students' needs in coursework, program planning, career options, and development issues.
- Faculty, professional advisers, and peers are involved in academic advising.

University academic advisers participate in an Academic Advising Network—a forum for sharing information and expertise across colleges and departments. Expect academic advisers at all levels to assist you in designing and implementing a program of study and related activities that will allow you to achieve your educational goals. Advisers expect you to prepare for program planning sessions by giving careful thought to possible course selections, program schedules, and short- and long-term education and career goals, and to come to appointments with pertinent academic records and materials.

Advisers—Advising for freshmen is coordinated by the Office of Lower Division Programs, 128 Lind Hall (612/624-2890). Every IT freshman is assigned to a team of approximately 100 students. During orientation, freshmen meet with their advisers and plan their fall schedule. Students on each

team take several courses in common. This encourages the formation of study and support groups. Freshmen must meet with a faculty adviser at least once each term to discuss their progress and plan their schedule for the following quarter.

All lower division students obtain advising through the Office of Lower Division Programs until admission to upper division.

Tutorial Assistance—IT provides peer tutorial assistance for its students in chemistry, computer science, mathematics, physics, and other IT courses. These teaching assistants, who are selected from junior and senior IT honor students, are trained, qualified, and willing to assist students on a one-on-one basis with problems in IT lower and upper division courses. Tutorial assistance is provided in various locations—on campus (150 Lind Hall, the Science & Engineering Library in 260 Walter Library, by appointment in 128 Lind Hall, and over the phone at 612/624-2890), in all residence halls, and at selected metropolitan high schools.

In addition, graduate teaching assistants provide tutorial service for computer science courses in offices near the Instructional Lab, 4-204 Electrical Engineering/Computer Science Building. Mathematics and physics graduate teaching assistants are available in 150 Lind Hall with the undergraduate teaching assistants. They offer help with coursework taught by the department with which they are associated.

Inquiries about tutorial programs should be made to the Office of Lower Division Programs, 128 Lind Hall.

IT Career Planning and Placement—The IT Career Planning and Placement Office, 50 Lind Hall, assists graduating seniors and advanced degree candidates seeking employment through a full range of services. Registration with the office soon after entering the University is recommended.

A wide variety of employers, representing local, state, and national organizations, visit 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 part-time or summer employment.

A course is taught each winter quarter for students needing assistance in career decision making. The course IofT 1222—Introduction to Careers in Science and Engineering (2 credits) is open to all IT students.

IT juniors and seniors who are seeking employment can enroll in IofT 3311—Developing Effective Job Search Skills (1 credit). This course is offered once a year.

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

Disability Services—The University's mission is to provide optimal educational opportunities for all students, including those with physical, sensory, learning, and/or psychological disabilities. The University recognizes that disabled students sometimes have unique needs that must be met for them to have access to campus programs and facilities. In general, University policy calls for accommodations to be made on an individualized and flexible basis. It is the responsibility of students to seek assistance at the University and to make their needs known.

One of the first places to seek assistance is Disability Services (DS). This office is provided by the University to promote program and physical access, which means ensuring the rights of disabled students and assisting the University in meeting its obligations under federal and state statutes. DS provides direct assistance such as information, referral, advocacy, support, and academic accommodations (e.g., interpreters, readers, tutors) for enrolled and prospective students, as well as consultation to faculty and staff to ensure access to their programs and facilities. The office will also assist disabled students in obtaining services from other University or community resources. Educational specialists are available to assist students with learning disabilities and sensory impairments; counselors provide services to students with physical and/or psychological disabilities as well as serve as a liaison between the

University and the Division of Rehabilitation Services. Campus accessibility guides are available and address such issues as building accessibility, handicapped parking, curb cuts, elevator locations, and accessible buses. For more information, contact Disability Services, 30 Nicholson Hall, 216 Pillsbury Drive S.E., Minneapolis, MN 55455 (612/626-1333, voice or TTY).

Grading

Grading System and Grade Point Average—Students should consult the *Class Schedule* for an explanation of the University's grading system.

Only credits taken on the A-F grading system are calculated in the grade point average (GPA). Each letter grade carries the following grade points per credit: A=4.00, B=3.00, C=2.00, D=1.00, and F=0.00. The GPA is determined by dividing the sum of the grade points earned by the sum of the credits completed.

With the S-N grading system, the N grade is assigned when a student does not earn an S and is not assigned an I. It stands for no credit, carries no grade points, and is not used in calculating the GPA.

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

New students in IT may take only one course 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 term 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 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 change from A-F to S-N or from S-N to A-F through the second week of a quarter, but not thereafter. A change from or to S-N registration in a given course must be made on a Course Request form.

S-N registration is indicated by inserting S-N in the grade option column on the Course Request form.

Incompletes—The I grade is assigned only 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 F 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 a grade. IT students who withdraw from a course following the end of the second week of a quarter up through the end of the sixth week receive this symbol, regardless of their academic standing in the class at the time of cancellation. Cancellations processed during the first two weeks of a quarter do not appear on a student's record. Cancellation after the first six weeks of a quarter is granted only with approval from the Student Affairs Office, 105 Lind Hall (624-8504). Such late cancellations are granted only under unusual circumstances.

To completely leave the University during a quarter, students must cancel all courses for which they are registered. They should notify the Student Affairs Office, 105 Lind Hall (624-8504), preferably in person.

Auditing—The symbol V indicates that the student is a visitor in a course and is taking it 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. Students who audit courses pay regular tuition and fees.

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 academic transcript.

Scholastic Policies

Special Examinations for Credit—Students who believe their knowledge of a subject is equal to that required to complete a particular course may request to take an examination for credit. Once approved in 105 Lind Hall, arrangements can be made with the appropriate department to take an examination. A $30 fee is assessed for each examination. Only currently enrolled students are eligible. Credit by special examination is not granted for language courses taken in high school.

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 1051-1052, 3100-3101
Chem 3301/3305, 3302/3306
EE 3009[1]
Geo 1001, 1002
Math 1151, 1251-1252-1261[2]
Math 1551H-1552H-1553H[3]
Phys 1251-1252-1253[3]
Phys 1254P-3512-3513

IT students must earn a grade of C or better in all 1xxx and 3xxx math, physics, and chemistry courses.

Upper Division—The upper division corresponds to the junior and senior year.

Freshmen and sophomores must apply for entry and are told at orientation what minimum GPA might be required. That GPA is calculated using the grades of all courses taken, including repeated courses. Students should file an application in 105 Lind Hall before completing their sophomore year.

Academic Difficulty: Probation and Drop Status—See your adviser regularly especially if you are having difficulty in any of your courses. IT's mechanism for dealing with academic difficulty is called academic probation.

There are three levels of probation: academic warning, probation contract, and suspension. A student is placed on *academic warning* if his/her quarterly or cumulative GPA is less than 2.00 but 1.50 or better. A student on academic warning must see an adviser in order to register and will be issued an override to register at their normal queued time. If the student's quarterly and cumulative GPAs at the end of the probationary quarter are 2.00, the student is removed from academic warning. If not, the student is placed on *probation contract.*

A student is also placed on probation contract if his/her quarterly or cumulative GPA is less than 1.50. A student on probation contract must complete a specific contract (E-100) for academic performance and will not be allowed to register for subsequent quarters until grades for the probationary quarter are received. If E-100 goals are met, and quarterly and cumulative GPAs are at least 2.00, the student is removed from probation. If goals are not met, the student is placed on *suspension.*

A student who is suspended may appeal the suspension. A determination of readmittance will be made jointly by the Student Affairs Office and the student's major department. Readmission is not automatic; to be readmitted, a student must show evidence of changes in circumstance that make it more likely that the student will succeed in the academic program.

Appeal Procedure—Go to the Student Affairs Office, 105 Lind Hall, and fill out a Scholastic Drop Appeal. Attach a transcript and other supporting material. You will be notified of the decision by mail.

Suspension Status—A suspended student may not reenter day school classes or take IT evening classes through Continuing Education and Extension unless granted permission by the Student Affairs Office and the department Scholastic Standards Committee.

Repeating Courses—Students are allowed to repeat courses in which they received a grade of D or less, and only the last grade earned is then used in computing their GPA and honor point deficiency. Students are not allowed to repeat courses in which they received a grade of C or better.

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

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[1] *A C grade or better in EE 3009 is required for admission to EE 3010.*

[2] *In order to continue in additional mathematics courses (in particular Math 3251 or Math 3261) or sequences, an IT student must earn at least a C grade in Math 1261.*

[3] *For continuation in physics sequences, an IT student must earn at least a C grade in Phys 1254.*

ROTC Courses—Grades received in all ROTC courses will be entered on the student's transcript and will be counted in the GPA calculation.

Changing Majors—To change majors within IT, students must petition requesting such a change. Forms are available in 105 Lind Hall. A transcript must accompany the petition.

Students who graduate from IT but continue to register for classes will automatically have their major changed to adult special (nondegree) unless they had previously been admitted to a second (double) major.

To change majors from IT to another college unit or campus within the University, students must apply for transfer through Student Relations, 150 Williamson Hall, 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.

Dean's List—Students whose quarterly GPA is 3.75 or better qualify for the Dean's List. Students must complete at least 12 credits A-F to be eligible.

Graduation—The bachelor's degree with professional designation will be recommended for students who have been formally admitted to the department from which she or he wishes to graduate, who earn a GPA of 2.00 or better, 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 Student Relations, 150 Williamson Hall, about a year before graduation.

Students with a GPA of 3.50 or better in their undergraduate work are granted their degree "with distinction." Students with a GPA of 3.80 or better in their undergraduate work are granted their degree "with high distinction."

Conduct and Discipline

The Institute of Technology assumes that all students who enroll in its programs are serious about their education and expects them to be responsible individuals who demand of themselves high standards of honesty and good personal conduct.

The Institute of Technology expects the highest standards of honesty and integrity in the academic performance of its students. Any act of scholastic dishonesty is regarded as a serious offense, which may result in expulsion. The Institute of Technology defines scholastic dishonesty as submission of false records of academic achievement; cheating on assignments or examinations; plagiarizing; altering, forging, or misusing a University academic record; taking, acquiring, or using test materials without faculty permission; acting alone or in cooperation with another to falsify records or to obtain dishonestly grades, honors, awards, or professional endorsement. Aiding and abetting a student in an act of scholastic dishonesty is also considered a serious offense.

The IT Student Conduct Committee, composed of faculty and students, hears cases of scholastic dishonesty. When charges are upheld, the student may be placed on disciplinary probation, failed in a course, suspended, or expelled.

A student has the right to a hearing and to appeal any disciplinary action. Copies of the procedures for cases of scholastic dishonesty are available in 105 Lind Hall upon request.

Disciplinary cases that are nonacademic in nature or that involve two or more colleges are referred to the Campus Committee on Student Behavior (612/624-6073).

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

Grievances

Students with complaints about academic policies have recourse through well-established grievance procedures. They are expected to confer first with the course instructor. If no

satisfactory solution is reached, the complaint should be presented to the department, school, or program head. If these informal processes fail to reach a satisfactory resolution, the department's grievance committee will hear the evidence. Advisers in 105 Lind Hall are competent sources for interpreting college procedures or regulations and can often suggest suitable alternatives when a problem is involved. Copies of the *Student Academic Grievance Policy* are also available in 105 Lind Hall.

Student Activities

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 conducting 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: American Chemical Society, American Institute of Chemical Engineers, Society of Physics Students, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society of Agricultural Engineers, American Institute of Aeronautics and Astronautics, American Institute of Industrial Engineers, and Institute of Electrical and Electronic Engineers. Additional professional societies include the Society of Women Engineers and Triangle.

Honorary Scholastic Societies—The honorary scholastic societies 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 societies 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). Of these honorary societies, 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 and Kappa Eta Kappa (Electrical Engineering), Pi Tau Sigma (Mechanical Engineering), and Sigma Gamma Tau (Aerospace Engineering and Mechanics).

Plumb Bob—Plumb Bob, a senior honorary leadership and service society, works to create and maintain a spirit of fellowship and cooperation among IT students and further the interests of IT and the University. Its members are chosen for their character, leadership, and service.

IT Student Board—The IT Student Board is the executive body of the students in the Institute of Technology. It represents students in matters affecting the general interests of IT and the University.

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. Many engineers obtain 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 examinations in the fundamentals, principles, and practice of engineering and who have demonstrated their competence by a specified number of years of appropriate experience. The fundamentals of engineering examination covers materials studied in undergraduate curricula. This examination is given in the spring and fall of every year and may be taken by students in their senior year. More information and

applications may be obtained from 50 Lind Hall or by writing to the Minnesota State Board of Architecture, Engineering, Land Surveying, Landscape Architecture and Interior Design, 133 7th Street East, St. Paul, MN 55101-2333 (612/296-2388).

UNITE Instructional Television—About 45 credit 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 TV 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 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 on company policy.

For more information, contact the Director, UNITE Instructional Television, 114 Lind Hall, 207 Church Street S.E., Minneapolis, MN 55455 (612/624-2332).

Curricular Requirements

Freshman Liberal Education Requirements

(effective fall 1994 and later for freshmen enrolling with fewer than 39 credits)

A liberal education introduces you to the modes of inquiry and subject matter of the major branches of knowledge, including the factual information and theoretical or artistic constructs that form their foundations; the "ways of knowing"—the kinds of questions asked and how insight, knowledge, and data are acquired and used; the changes over time of their central ideas or expressive forms; and the interrelationships among them and with human society in general. To these ends, study by all undergraduate students on the Twin Cities campus is guided by a common framework.

The Diversified Core Curriculum

Physical and Biological Sciences. Comprehension of physical and biological principles; understanding of and ability to use the methods of scientific inquiry—the ways in which scientists investigate physical and biological phenomena; and appreciation of the importance of science and the value of a scientific perspective.
Requirement: A minimum of three courses totaling at least 12 credits, including one course with a laboratory or field experience in the physical sciences and one course with a laboratory or field experience in the biological sciences.

History and Social Sciences. Knowledge of how historians and social scientists describe and analyze human experiences and behavior; study of the interrelationships among individuals, institutions, structures, events, and ideas; understanding of the roles individuals play in their historical, cultural, social, economic, and political worlds.
Requirement: A minimum of three courses totaling at least 12 credits, including one course with historical perspective.

Arts and Humanities. Understanding of approaches to the human condition through works of art, literature, and philosophy; knowledge of how artists create and humanistic scholars think; ability to make aesthetic judgments.
Requirement: A minimum of three courses totaling at least 12 credits including courses in two of the following: literature, philosophical perspective, and visual or performing arts.

Mathematical Thinking. Acquisition of mathematical modes of thinking; ability to evaluate arguments, detect fallacious reasoning, and evaluate complex reasoning chains; appreciation of the breadth of applications of mathematics and its foundations.
Requirement: A minimum of one course totaling at least four credits.

The Designated Themes of Liberal Education

The designated themes of liberal education offer a dimension to liberal learning that complements the diversified core curriculum. Each of the themes focuses on an issue of compelling importance to the nation and the world, the understanding of which is informed by many disciplines and interdisciplinary fields of knowledge.
Requirement: A minimum of six courses (or five courses if one includes an approved practicum), including one course in each of the following:

Cultural Diversity. Understanding of the roles gender, ethnicity, and race play in structuring the human experience in and developing the social and cultural fabric of the United States.

International Perspectives. Comprehension of the ways in which you are part of a rapidly changing global environment dominated by the internationalization of most human endeavors.

Environment. Knowledge of the interaction and interdependence of the biophysical systems of the natural environment and human social and cultural systems.

Citizenship and Public Ethics. Reflection on and determination of a clearer sense of your present and future civic relationships and your obligations to the community.

Writing Skills

The ability to communicate effectively is a hallmark of a liberally educated individual and a key to a successful and satisfying life. To encourage refining of writing skills, the liberal education curriculum includes both writing courses and writing across the curriculum.
Requirement: All students will complete the writing requirement specified by the college awarding their baccalaureate degree.

You may satisfy the liberal education requirements with a number of courses and credits different from those of other students because some courses serve multiple goals in the curriculum; e.g., some courses will satisfy a diversified core requirement and a designated theme requirement, and other courses will satisfy the requirements for each of two themes. Thus, you may satisfy the designated theme requirements with a smaller number of courses than is stated in the requirement. Each quarter, the *Class Schedule* will publish the requirements and list all courses that satisfy them. In addition, the *Class Schedule* will list which of these courses are offered that quarter and which are tentatively scheduled for the subsequent quarters during the academic year.

Students admitted to IT before fall quarter 1994 will follow the old liberal education requirements found in *A Student Guide to Liberal Education Courses for Students in the Institute of Technology,* available in 105 Lind Hall and department offices.

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.

A constantly changing professional field, aerospace engineering 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 four-year program leading to the bachelor of aerospace engineering and mechanics (B.A.E.M.) degree provides 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. There are many options available permitting students to prepare for careers in the many branches of aeronautical engineering and aerospace engineering, and in diverse fields such as oceanography, meteorology, environmental engineering, transportation systems, and bioengineering.

The department offers an optional engineering intern program in the upper division. This program allows students to obtain practical work experience in industry in quarters (including summer) that alternate with University academic work during the last two years of study. Prospective participants should contact the director of the program for information in the fall of their sophomore year.

A recommended program totaling 104 quarter credits 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. The program is accredited by the Engineering Accreditation Commission of ABET.

Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.

Lower Division

	Credits
Comp 1011—Writing Practice I	5
Liberal education electives	16
Math 1251-1252-1261	12
Math 3251, 3252, 3261	12
Phys 1251-1252-1253-1254	16
Chem 1051-1052	8
EE 3009, 3005, 3006—Circuits and Electronics	9
CSci 3101—A FORTRAN Introduction to Computer Programming	4
MatS 3400—Mechanical Properties of Materials	4
AEM 1015—Statics	4
AEM 3005—Introduction to Flight	4
AEM 3036—Dynamics	4
	98

Upper Division

	Credits
Comp 3031—Technical Writing	4
Liberal education electives	12
Required technical courses	64
AEM 3016—Deformable Body Mechanics (4)	
AEM 3401—System Dynamics (4)	
AEM 5200, 5202, 5204—Fluid Mechanics I-III (12)	
AEM 5205—Aerospace Propulsion	
AEM 5206—Lifting Surfaces (4)	
AEM 5300—Flight Mechanics (4)	
AEM 5319—Dynamics and Control of Aerospace Vehicles (4)	
AEM 5329, 5330—Design (8)	
AEM 5515—Aerospace Structures (4)	
AEM 5630, 5631, 5632—Senior Lab I-III (8) (only 2 of 3 required)	
ME 3301—Thermodynamics (4)	
ME 3305—Propulsion for Aerospace Engineering (4)	
ME 5342—Heat Transfer (4)	
Technical electives	16
Three upper division AEM or other IT courses (12)	
Solids, Materials, or Structures course—AEM 5516, 5518, 5580, 5581 (4)	
	96

Agricultural Engineering

See Biosystems and Agricultural Engineering.

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. A double major in astrophysics and physics can be completed.

General Requirements

Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.

	Credits
Mathematics	
Math 1251-1252-1261	12
Math 3251-3252-3261	12
Two additional 5xxx courses	8
Astrophysics and Physics	
Ast 3051—Astrophysics	4
Ast 5162 plus one additional Ast 5xxx course	8
Phys 1251-1252-1253-1254—Introductory Physics	16
Phys 3512-3513—Modern Physics	6
Phys 3515-3516—Modern Physics Lab	4
Phys 3601—Special Relativity	3
Phys 5021-5022—Introduction to Analytic Mechanics	8
Phys 5023-5024—Introduction to Electric and Magnetic Fields	8
Ast 5990—Directed Research	3
Free electives to total 180 credits	44-48
Subtotal	*180 or 184*
English and/or foreign language as required	0-17
	180-201

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
One additional 5xxx Ast course
Phys 5201-5202—Thermal and Statistical Physics
Phys 5101-5102—Quantum Mechanics
Phys 5801—Modern Optics
Phys 5121-5122-5123—Methods of Experimental Physics

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

Biosystems and Agricultural Engineering

Biosystems and agricultural engineers apply engineering principles to environmental, agricultural, and other biosystems involving soil, water, and air for the production and processing of plant, animal, food, and related biological materials. They use their knowledge and skills to enhance environmental quality while improving the efficiency and profitability of agricultural production systems; the quality of biological, agricultural, and food products; and the quality of life of those working in and benefiting from agriculture. These objectives are met by developing, improving, and applying processes, machines, structures, and their management to achieve a balance among production, use, profitability, and quality of life.

Biosystems and agricultural engineers are members of a diverse profession made up of environmental and natural resource agencies, agricultural and food industries, and consulting firms that work to benefit the general public. They apply environmental, agricultural, biological, and physical sciences and engineering science and design to solve problems in agricultural and biological production and processing systems in a safe, environmentally-conscious manner. Biosystems and agricultural engineers play a critically important role in providing high-quality food for the world.

The agricultural engineering curriculum can be completed in four years by earning a minimum of 190 credits. Emphasis is on the physical and engineering sciences and engineering design. Study of biology, agricultural science, communications, social science, and humanities is included to provide a liberal education and to enable agricultural engineers to work effectively with professionals in many disciplines (see page 24 for liberal education requirements). The program provides students with a fundamental background for continued professional growth and prepares them to contribute to an ever-changing society.

The curriculum includes emphases in environment, agricultural systems, and biological systems. Students, with the assistance of an adviser, plan a curriculum tailored to their individual interests in one of these three emphases. Students can choose additional courses in interest areas including land, soil, and water resources; waste management; food engineering; bioprocessing; environmental control of animal buildings; agricultural structures; greenhouse engineering; forest engineering; aquaculture engineering; agricultural safety; and machinery for production and processing of biological, agricultural, and food materials.

Engineering internships that supplement classroom instruction by providing practical education and experience with an employer are available. Students may begin their internships in the summer following either their first or second year.

The agricultural engineering program is accredited by the Engineering Accreditation Commission of ABET.

Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.

Lower Division

	Credits
Comp 1011—Writing Practice I *or* Rhet 1101—Writing to Inform and Persuade	4-5
Math 1251-1252—Differential and Integral Calculus	8
Math 1261—Algebra and Geometry of Euclidean Space	4
Math 3261—Differential Equations with Linear Algebra	4
Math 3251—Vector Differential Calculus	4
Math 3252—Multivariable Integral Calculus	4
Phys 1251-1252-1253—General Physics I-II-III	12
Chem 1051-1052—Chemical Principles I-II	8
Biol 1009—General Biology	5
AgEn 1060—Agricultural Engineering Orientation	1
AEM 1015—Statics	4
AgEn 3031—Computations in Agricultural Engineering	4
AEM 3016—Deformable Body Mechanics	4
CE 3400 *or* AEM 3200—Fluid Mechanics	4
CSci 3101, CSci 3102 *or* CSci 3113—Computer Programming	4
ME 3301—Thermodynamics	4
Liberal education electives	16
	94-95

Upper Division

	Credits
Comp 3031—Technical Writing for Engineers *or* Rhet 3562—Writing in Your Profession	4
EE 3009-1400—Linear Circuits I, Circuits Laboratory	5
ME 5342—Heat Transfer *or* CE 5504—Mass Transport With Environmental Applications	4
ME 3900 or Stat 3091—Statistics	4
Biological science elective (at 3xxx or 5xxx level; including agricultural science courses with significant biological content)	7-8
AgEn 3052—Engineering Principles of Soil-Water-Plant Systems	4
AgEn 3150—Biology for Engineers	4
AgEn 5891-5892—Senior Design I-II	5
Two courses from:	8
AgEn 5070—Automatic Controls and Instrumentation	
AgEn 5072—Finite Element Methods	
AgEn 5074—Microcomputer Interfacing	

Students must follow one of the following emphases:

1.	*Environment*	
	ME 1025—Engineering Graphics	4
	AEM 3036—Dynamics	4
	AgEn 5540—Watershed Engineering	4
	AgEn 5550—Water Management Engineering *or* AgEn 5910—Agricultural Management Engineering	4
	Agricultural engineering elective*	4
	Engineering electives in environmental area*	12
2.	*Agricultural Systems*	
	ME 1025—Engineering Graphics	4
	AEM 3036—Dynamics	4
	Agricultural engineering electives*	12
	Engineering electives in agricultural systems*	12
3.	*Biological Systems*	
	Chem 3301-3302—Organic Chemistry I-II	8
	Chem 3305-3306—Organic Chemistry Lab I-II	4
	BioC 3021—Biochemistry	4
	AgEn 5751—Biochemical Engineering I	3
	Agricultural engineering electives*	8
	Engineering electives and biological systems	8
Liberal education electives		11-12
Electives to consider student interest and to meet graduation requirements of 190 credits		2-8
		95-96

Electives are chosen to develop further professional competence in an area of particular interest to the student. Sample programs are available from the department office or from individual advisers.

* *Engineering electives to satisfy ABET engineering topics requirements*

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 on applications of chemistry, physics, mathematics, economics, and increasingly, biology and biochemistry. Because of this broad-based foundation that emphasizes basic and engineering sciences, the chemical engineer is considered the universal engineer.

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, product innovation, marketing, management, consulting, teaching. 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, materials science, business administration, or patent law.

Chemical engineering deals with unit operations such as materials handling, mixing, fluid flow and metering, heat exchange, extrusion and coating, chemical vapor deposition, filtration, drying, evaporation, distillation, absorption, extraction, crystallization, ion exchange, combustion, catalysis, and processing in chemical and biochemical 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 complex or large-scale industrial process requires a chemical engineer who has a complete and quantitative understanding of the engineering principles 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, fertilizers, paint pigments, ceramics, semiconductors, and other electronic materials; in the manufacture of organic products—polymer fibers, films, coatings, textiles, cellulose, paper, plastics, agricultural chemicals, pharmaceuticals, coal-based fuels, petrochemicals; 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 including antibiotics and feed supplements. 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 use 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 use as well as storage of radionuclides and fission products.

The chemical engineer may also enter the field of biotechnology, in which applications include using of the activities of microorganisms and cultured cells, enzyme engineering and other areas of emerging biotechnology, manufacturing foods, and designing prosthetic devices and artificial human organs.

Degree Requirements—To receive the bachelor of chemical engineering degree, students must normally complete required and elective coursework totaling 192 credits. Students must satisfy the University minimum liberal education requirements and complete a coherent degree program of science and technical courses, including an elective area of emphasis.

Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.

The student, together with her or his adviser, plans the degree program in stages: a course plan is submitted every quarter for the first two

years and yearly, in spring, after that. 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 department office, 151 Amundson Hall. Advisers and the department's director of undergraduate studies can be contacted through the same office. The program is accredited by the Engineering Accreditation Commission of ABET.

Cooperative Programs—Intern programs combining work with academic study may be arranged by a student with an appropriate employer when a job offers professional training in the field of study. Such arrangements can receive department approval and cooperation. The department does not find jobs for students, but does encourage them to find employment that can qualify for cooperative status.

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

Lower Division

First Year	Credits *f*	*w*	*s*
Comp 1011—Writing Practice I	5	...	...
Math 1251-1252-1261	4	4	4
Chem 1051-1052, 3301, 3305—Chemical Principles I-II, Organic Chemistry	4	4	6
Phys 1251-1252—General Physics, Laboratory	...	4	4
Liberal education electives	4	4	4
	17	16	18

Second Year	Credits *f*	*w*	*s*
Chem 3302, 3306, 5126—Introductory Organic Chemistry II with Lab and Analytical Chemistry	6	...	4
Phys 1253	4	...	...
Math 3251, 3261, 3252	4	4	4
Biol 1009—General Biology	...	5	...
ChEn 3001, 5101—Stoichiometry and Balances	...	2	4
Liberal education electives	4	4	4
	18	17	16

Note that the lower division curriculum in chemical engineering is nearly the same as the lower division curriculum in chemistry. It differs from those in other engineering fields because more chemistry coursework is required.

Upper Division

Third Year	Credits *f*	*w*	*s*
ChEn 5001, 5102, 5103—Computation Balances, Fluid Mechanics, Heat and Mass Transfer	4	4	4
Comp 3015 or 3031	4	...	...
ChEn 5401—Chemical Engineering Laboratory	...	...	4
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 lab	...	4	1
Emphasis electives[2]	...	4	...
	16	16	13

Fourth Year	Credits *f*	*w*	*s*
ChEn 5104—Unit Operations and Separation Processes	4	...	...
ChEn 5501, 5502—Process Evaluation and Design	...	4	4
ChEn 5301—Chemical Reactor Analysis	4		...
ChEn 5601—Process Control	...	4	...
ChEn 5402, 5604—Chemical Engineering Laboratory[1]	4	...	2
Chem 5533	...	4	...
Emphasis electives[2]	4	4	8
	16	16	14

[1] *Programs normally include at least one ChEn lab course in addition to ChEn 5401 and 5402.*

[2] *A normal program of technical electives consists of five courses in a coherent field; at least three of these must be 5xxx courses.*

Chemistry

Chemistry probes the fundamental concepts of nature and helps us understand the world around us. It deals with all substances at the molecular level: their composition, their properties, and how they are transformed into new substances. Chemistry is a central science of great importance to society. It provides a broad range of opportunities in many specialized fields, including biotechnology, polymer chemistry, environmental chemistry, materials chemistry, and medicine.

After graduating with a bachelor's degree, many chemistry majors go on to graduate or professional schools to pursue advanced degrees. Other graduates find employment in industry, education, or government.

The chemistry curriculum includes courses in chemistry, physics, mathematics, and the liberal arts. Specific requirements for the degree are:

- A minimum of 180 credits. All required courses excluding freshman writing practice must be taken A-F. A grade of C or better is required in all technical courses.
- Freshman writing practice (or exemption) and one advanced writing course (9 credits).
- One year of calculus-based physics (12 credits).
- Five quarters (20 credits) of mathematics.
- 52-54 credits of chemistry.
- Three quarters of advanced technical electives (9-12 credits) selected from 3xxx- and higher-level courses of 3 credits or more in chemistry and related areas.
- Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.
- Electives (to total 180 credits), chosen by the student in consultation with her or his adviser, but otherwise without restriction.

By selecting appropriate electives it is possible for a student to construct a program with emphasis in special interest areas, such as bioscience, chemical physics, education, enviornmental chemistry, and materials chemistry. Other special interest areas are also possible and chemistry advisers can be helpful in designing such programs. It is also possible for a chemical engineering major to obtain a degree in chemistry in the same time normally required for the engineering degree. This double major option requires careful course planning and should be discussed as early as possible with a chemistry adviser.

All chemistry majors are advised by faculty and staff in the chemistry advising office. Each student plans his or her degree program by submitting one-year plans in consultation with an adviser. The final one-year degree plan must be certified for graduation by the department. This must be accomplished early in the last year.

Transfer Students—Students planning to transfer from another institution or campus should take courses that are equivalent to those required for this degree program. The chemistry advising office will advise students on the equivalency of courses. It is recommended that potential transfer students contact this office concerning the proposed transfer of courses before planning a curriculum. This can be done in writing, during a visit, or over the phone: Chemistry Undergraduate Advising, 135 Smith Hall, Department of Chemistry, 207 Pleasant Street S.E., Minneapolis, MN 55455 (612/624-8008).

Special Opportunities—The chemistry department offers opportunities for undergraduate research with many of its faculty. Professional activities are also available through membership in the Student Affiliate Program of the American Chemical Society. In addition, the department offers a number of scholarships and awards for outstanding chemistry majors. Information on these opportunities may be obtained from the chemistry advising office.

Lower Division

	Credits
Chem 1051-1052—Chemical Principles I-II	8
Chem 3301-3302—Organic Chemistry I-II	8
Chem 3305-3306—Organic Chemistry I-II Labs	4
Chem 3701—Introduction to Inorganic Chemistry	4
Math 1251-1252-1261—Calculus I-III	12
Math 3251—Multivariable Differential Calculus and advanced math elective[1]	8
Phys 1251-1252-1253—General Physics I-III and Labs	12
Comp 1011—Writing Practice I	5
Electives[2]	29
	90

Upper Division

	Credits
Chem 5130-5131—Analytical Chemistry and Lab	5
Chem 5501 or 5534—Introduction to Thermodynamics and Kinetics *or* Chemical Thermodynamics	4
Chem 5502 or 5533 or 5535—Introduction to Quantum Theory and Spectroscopy *or* Quantum Chemistry *or* Statistical Mechanics and Reaction Kinetics	4
Comp 3015—Writing About Science	4
Advanced chemistry electives, lectures[3]	6-8
Advanced chemistry electives, labs[4]	9
Advanced technical electives[5]	9-12
Electives[2]	44-49
	90

Civil Engineering

(Department of Civil 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 192 credits. The first two years of the curriculum are similar to the first two years of the curricula in other IT engineering departments. Students may transfer to civil engineering from another IT engineering department, another University campus or college, or another academic institution. Students who transfer to the program after completing the first two years at another institution must complete a course in statics (AEM 1015), which is a prerequisite for many third-year CE courses, before entering the University if they expect to complete the program in two additional years. The last two 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 pre-stressed 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.

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 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.

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[1] *Advanced math elective (one course required) selected from Math 3252, 3261, Stat 3011, or PubH 5450.*

[2] *Elective credits must include courses to satisfy the liberal education requirements.*

[3] *Advanced chemistry electives, lecture (two courses required) selected from 3303 or any non-required 5xxx chemistry course.*

[4] *Advanced chemistry electives, lab (three courses required) selected from Chem 3336, 5140, 5540, 5740, 5970, or any of the following can count as one advanced lab: ChEn 5401, 5402, MatS 5200, 5202, 5450, 5613.*

[5] *Advanced technical electives (three courses required) selected from 3xxx- and higher-level courses of 3 credits or more in Chem, BioC, Biol, GCB, ChEn, MatS, Math, Phys, PubH, and Stat.*

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.

Upper division civil engineering students with a cumulative GPA of 2.50 may enter an engineering intern program after completing at least one quarter of study in IT. Participants alternate study quarters with a six-month work period, for which they can earn 4 credits. For more information, contact the Director of the Civil Engineering Intern Program, Department of Civil Engineering, University of Minnesota, 122 Civil Engineering, 500 Pillsbury Drive S.E., Minneapolis, MN 55455.

The program is accredited by the Engineering Accreditation Commission of ABET.

Course Requirements

General requirements for the bachelor of civil engineering degree are listed below. The lower division program includes coursework in basic and engineering science. The upper division program includes coursework in additional engineering science and applied engineering subjects. By selecting appropriate technical electives in consultation with their advisers, students can emphasize various special interest areas in their upper division curriculum.

Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.

Credit and course requirements are subject to change by faculty action and may affect requirements for graduation. For a complete description of the current Civil Engineering Program, students should obtain a curriculum brochure in 122 Civil Engineering.

Lower Division

	Credits
Comp 1011—Writing Practice I	5
Math 1251-1252-1261—One-Variable Differential *and* Integral Calculus I-II *and* Algebra and Geometry of Euclidean Space	12
Math 3251-3252-3261—Multivariable Differential *and* Integral Calculus *and* Differential Equations with Linear Algebra	12
Physics 1251-1252-1253—General Physics	12
Chem 1051-1052—General Principles	8
Geo 1001, 1021 or 1111—Physical Geology	5
AEM 1015—Statics	4
AEM 3016—Deformable Body Mechanics	4
AEM 3036—Dynamics *or* ME 3301—Thermodynamics[1]	4
Stat 3091—Probability and Statistics	4
CE 3020—Computer Applications in Civil Engineering or CSci 3101, 3102 or 3113—FORTRAN, PASCAL, or C Programming	4
CE 3400—Fluid Mechanics	4
Liberal education electives	16
	94

Upper Division

	Credits
CE 3100—Introduction to Surveying and Mapping	4
CE 3200—Introduction to Transportation Engineering	4
CE 3300—Soil Mechanics	4
CE 5002—Engineering Economics	2
One course from the following list: CE 5301—Applied Soil Mechanics; CE 5425—Groundwater Mechanics; GeoE 5302—Applied Rock Mechanics	4
CE 5401—Water Resources Engineering	4
CE 5405—Hydrology and Hydrologic Design	4
CE 5500—Analysis and Design of Water Supply Systems	4
CE 5501—Analysis and Design of Wastewater Systems	4
CE 5603—Introduction to Construction Materials	4
CE 5600—Linear Structures Systems	4
CE 5610—Design of Metal Structures	4
CE 5611—Design of Reinforced Concrete Structures	4
Technical electives[2]	32
Liberal education electives	12
Free electives	4
	98

Master's Degree Programs

Because of the rapid development in technology, many students prepare themselves for advanced professional work by completing graduate study. Two master's degree programs, the M.S. and M.C.E., are available. Each requires about two years to complete. Information about these programs will be provided by the director of graduate studies of the department.

[1] *Students with an interest in Environmental Engineering may substitute CE 5506—Environmental Water Chemistry or CE 5515—Water and Wastewater Microbiology for the Dynamics/Thermodynamics requirement.*

[2] *Students may obtain guidelines for satisfying the technical electives in 122 Civil Engineering.*

Computer Science

Computer science is concerned with the study of the hardware, software (programming), and theoretical aspects of high speed computing devices and with the application of these devices to the solution of a broad spectrum of scientific, 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 *College of Liberal Arts Bulletin.* Both programs give students 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 students to develop a concentration within computer science or in interdisciplinary areas involving the applications of computers. This should prepare students for a variety of industrial, government, and business positions involving use of the computer or for graduate work in the field.

The four-year IT curriculum leads to the bachelor of science in computer science (B.S.) 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 188 credits is 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 A-F and passed with a C or better, unless particular courses are offered S-N only.

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 coursework is roughly equivalent to that required by the Institute of Technology. Most transfer students have not studied the material covered in CSci 3311, 3316, 3317, 3321, 3322 and 3327; 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 department office for information.

Lower Division

	Credits
Comp 1011—Writing Practice I	5
Math 1251-1252-1261—One-Variable Differential *and* Integral Calculus I-II *and* Algebra and Geometry of Euclidean Space *or* honors equivalents	12
Math 3251-3261—Multivariable Differential Calculus *and* Differential Equations With Linear Algebra *or* honors equivalents	8
Physics 1251-1252-1253—General Physics I-III	12
Stat 3091, 5121 or 5131—Introduction to Probability and Statistics, Theory of Statistics[1]	4
CSci 3311—Discrete Structures of Computer Science	4
CSci 3316—Introduction to the Structure of Computer Programming I	4
CSci 3317—Structure of Computer Programming II	4
CSci 3321—Algorithms and Data Structures I	4
CSci 3322—Algorithms and Data Structures II	4
CSci 3327—Introduction to the Organization of Computer Systems	4
Liberal education electives	16
Electives	12
	93

Upper Division

	Credits
Comp 3031—Technical Writing for Engineers	4
Liberal education electives	11
Electives	28
Required technical courses	
CSci 5102—Structure and Programming of Software Systems II	4
CSci 5106—Higher Level Languages	4
CSci 5201—Introduction to Computer Architecture	4
CSci 5301—Numerical Computation	4
CSci 5400—Introduction to Automata Theory	4
Upper Division Option	32
Elective courses that form a coherent program in computer science or application areas; for example, artificial intelligence, computer design and engineering, human-computer interaction, management information systems, mathematics of computation, software systems, or theory of computation. These courses may be selected from additional 5xxx CSci courses and adviser-approved 5xxx courses from other departments. At least 16 credits must be from computer science. See option program information available in department office	
	95

[1] *Students intending to complete additional work in statistics must take Stat 5121 rather than Stat 3091.*

Electrical Engineering

The electrical engineering program prepares its graduates for careers in electrical engineering and provides a foundation for continued professional development.

The electrical engineering curriculum offers students an opportunity to concentrate in one of several specialized areas, including biomedical engineering, communications, computer engineering, control systems, electric energy systems and power electronics, microelectronic devices and circuit design, optics and magnetic recording, and signal processing. The guidelines for selection of elective courses provide latitude to tailor the program to a wide variety of particular interests within the field of electrical engineering.

An honors program and an engineering co-op program are available to qualified upper division students. The honors program offers an opportunity for greater elective freedom culminating in an individual honors project completed under faculty guidance. The engineering co-op program offers industrial work experience and some financial support through alternate quarters of on-campus study and off-campus industrial assignment during part of the two-year period.

The degree of bachelor of electrical engineering (B.E.E.), granted after completion of the four-year curriculum, requires completion of a minimum of 192 quarter credits. Further information about the B.E.E. program is given in the *EE Curriculum Guide,* which can be obtained from the Department of Electrical Engineering, 4-178 Electrical Engineering/Computer Science Building, University of Minnesota, 200 Union Street S.E., Minneapolis, MN 55455.

For EE majors, all EE courses must be taken A-F except EE 1000, EE 3470 and EE 3471; also, all required technical courses must be taken A-F except those offered S-N only. A B.E.E. degree candidate must have zero or positive cumulative honor points in all 3xxx and 5xxx University EE courses.

The program is accredited by the Engineering Accreditation Commission of ABET.

Lower Division

	Credits
Comp 1011—Writing Practice I	5
Math 1251-1252-1261—One-Variable Differential *and* Integral Calculus I-II *and* Algebra and Geometry of Euclidean Space *or* honors equivalents	12
Math 3251-3252-3261—Multivariable Differential *and* Integral Calculus *and* Differential Equations with Linear Algebra *or* honors equivalents	12
Physics 1251-1252-1253, 3501—General Physics I-III, Modern Physics	16
Chem 1051-1052—Chemical Principles I-II	8
CSci 3113—Introduction to Programming in C	4
CSci 3321—Algorithms and Data Structures I	4
EE 1400—Circuits Laboratory	1
EE 3009-3010—Linear Circuits I-II	8
EE 3351, 3352—Introduction to Logic Design, Introduction to Microprocessors	8
Liberal education electives	12
Technical elective	4
	94

Upper Division

	Credits
EE 3011, 3012—Signal Analysis, System Design	8
EE 3060—Semiconductor Devices	4
EE 3061; 3062—Analog Electronics, Digital Electronics	8
EE 3110-3111—Electric and Magnetic Fields, Electromagnetic Waves	8
EE 3400-3401-3402—Junior EE Laboratory	6
Technical Electives	8
Comp 3031—Technical Writing for Engineers	4
Senior Technical Program	28
Electives (including required liberal education courses)	24
	98

In addition to the regular program described above, the Department of Electrical Engineering intends to offer an option in computer engineering beginning fall 1995. The option combines core courses from electrical engineering and computer science, allowing more technical electives to be taken from computer science. The option is for students who want to specialize in areas such as computer design, instrumentation, VLSI design, computer-aided design, and systems areas. Students choosing this option will receive a B.E.E. degree with a computer engineering emphasis.

Lower Division

	Credits
Comp 1011—Writing Practice I	5
Math 1251-1252-1261—One-Variable Differential	12
Math 3251-3252-3261—Multivariable Differential and Integral Calculus and Differential Equations With Linear Algebra	12

Physics 1251-1252-1253—General Physics I-III 12
Chem 1051—Chemical Principles I 4
CSci 3113—Introduction to Programming in C 4
CSci 3316-3317—Structure of Computer Programming I-II 8
EE 1400—Linear Circuits Laboratory 1
EE 3009-3010—Linear Circuits I-II 8
EE 3351—Introduction to Logic Design 4
EE 3352—Introduction to Microprocessors 4
Liberal education electives 16

Upper Division

Junior *Credits*
CSci 3311—Discrete Structures of Computer Science . 4
CSci 3321-3322—Algorithms and Data Structures I-II 8
EE 3011—Signal Analysis 4
EE 3021—Probability in Engineering Systems 4
EE 3061-3062—Analog Electronics and Analog and Digital Electronics 8
EE 3110—Transmission Lines 4
EE 3400, 3401—Junior Electrical Engineering Laboratory 4
EE 5358—Digital Design with Programmable Logic ... 4
Comp 3031—Technical Writing 4
Technical elective 4

Senior Year
CSci 5102—Structure and Programming of Software Systems 4
EE 5355—Microprocessor Interfacing and System Design 4
EE 5450—Senior Design Project 2
Senior technical electives 28
Free elective 4
Liberal education electives 7

Geological Engineering

(Department of Civil Engineering)

A geological engineer applies the principles of engineering and science to the problems of planning, analysis, design, construction, and operation of facilities on and under the surface of the Earth. Geological engineering is based on applications of geology, physics, chemistry, mathematics, and engineering mechanics. As can be seen in the course requirements, a geological engineer has many of the skills required of a civil engineer, an environmental engineer, and a geologist; however, the geological engineer is uniquely qualified to work at the interface of these disciplines.

Within the geological engineering program there are two degree paths: the geoenvironmental option and the geomechanics option. The geoenvironmental option focuses on: 1) soil and groundwater contamination characterization, modeling, and remediation technologies; 2) solid and hazardous waste characterization, management, and disposal. The geomechanics option focuses on: 1) foundations for buildings, bridges, roads, and dams; 2) the analysis and design of surface and subsurface excavations; 3) the evaluation of natural geologic hazards.

Geological engineers work in many branches of industry and government. The most common employment for geological engineering graduates is within the private sector as a consulting engineer. Many geological engineering graduates also work at international, national, state, and local agencies involved with environmental protection, energy conservation and generation, and the conservation and exploitation of natural resources.

Geological engineering students may enter an engineering intern program after completing approximately five quarters of study. Participants alternate study quarters with a six-month work period, for which they can earn four credits. For more information, contact the director of the Engineering Intern Program in the Department of Civil Engineering, 122 Civil Engineering (612/625-5522).

Due to a collaborative agreement with the Department of Geology and Geophysics, it is possible to obtain a double degree—B.S.Geol. and B. Geological Engineering—with an additional one quarter of study during the regular academic year beyond the requirements for the geological engineering degree, plus geology summer field camp.

The program is accredited by the Engineering Accreditation Commission of ABET.

Course Requirements

The bachelor of geological engineering degree program requires a minimum of 191 credits. The first two years of the curriculum are almost identical to the first two years of the civil engineering program, and similar to the first two years of the curricula in other IT engineering departments. Students may transfer to geological engineering from another IT engineering program, University college or campus, or academic institution.

By selecting appropriate technical electives, in consultation with their adviser, students can

emphasize various special interest areas in their upper division curriculum. With few exceptions, all upper division geological engineering, civil engineering, and geology courses may be used to fulfill the technical elective requirements, in addition to many courses from other IT departments. However, students' final programs must satisfy the detailed curricular requirements specified by ABET for a geological engineering degree. Students may obtain guidelines for satisfying the technical electives requirements in 122 Civil Engineering.

The following listings include the required courses for each of the two options within the geological engineering program. Credit and course requirements are subject to change by faculty action and may affect requirements for graduation. For a complete description of the current geological engineering program, students should obtain a curriculum brochure in 142 Civil Engineering.

Lower Division

	Credits
Comp 1011—Writing Practice I	5
Math 1251-1252-1261—One-Variable Differential *and* Integral Calculus I-II *and* Algebra and Geometry of Euclidean Space	12
Math 3251-3252-3261—Multivariable Differential *and* Integral Calculus *and* Differential Equations with Linear Algebra	12
Physics 1251-1252-1253—General Physics I-III	12
Chem 1051-1052—General Principles I-II	8
Geo 1001 or 1111—Physical Geology	5
Stat 3091—Probability and Statistics *or* ME 3900—Engineering Statistics	4
AEM 1015—Statics	4
AEM 3016—Deformable Body Mechanics	4
CE 3020—Computer Applications I	4
CE 3400—Fluid Mechanics	4
Liberal education electives	16
Geoenvironmental option:	
CE 5506—Environmental Water Chemistry	4
Geomechanics option: AEM 3036—Dynamics	4
	94

Upper Division

	Credits
Comp 3031—Technical Writing for Engineers	4
Geo 3102—Petrology	4
Geo 3401—Mineralogy	4
Geo 5201—Structural Geology	4
Geo 5515—Geophysical Exploration	4
One course from the following	
Geo 5251—Geomorphology	
Geo 5261—Glacial Geology	
Geo 5651—Sedimentology	4
Geo 5010—Engineering Field Geology	2
CE 3300—Soil Mechanics	4
CE 5405—Hydrology and Hydrologic Design	4
CE 5425—Groundwater Mechanics	4
GeoE 5262—Geological Engineering Analysis	4
GeoE 5555—Engineering Geostatistics	4
GeoE 5700—Systems Analysis	4
Technical electives	16
Liberal education electives	11
Geoenvironmental option:	
CE 5401—Water Resource Engineering	4
CE 5426—Groundwater Modeling[1]	4
CE 5510—Solid and Hazardous Waste	4
CE 5501—Wastewater Systems or	
CE 5515—Engineering Microbiology	4
CE 5540—Groundwater Soil Pollution Abatement	4
Geomechanics option:	
CE 3100—Surveying and Mapping	4
CE 5301—Applied Soil Mechanics	4
GeoE 5218—Design of Underground Excavations in Rock	4
GeoE 5302—Applied Rock Mechanics	4
GeoE 5437—Computer Applications II	4
	97
Total	*191*

[1] *Students may substitute CE 5402 for CE 5426 with adviser approval.*

Geology and Geophysics

The Department of Geology and Geophysics offers two undergraduate programs, one in geology and one in geophysics. A minimum of 182 credits is required for completion of the B.S.Geol. and 186 credits for the B.S.Geophys.

Geology is the study of the composition, structure, and history of the Earth and of the processes that operate on and within it, with emphasis on the crust. The department's program places strong emphasis on the application of physics, chemistry, and biology to understanding the Earth.

Geophysics is the study of the physical structure and properties of the Earth through the application of the principles and techniques of classical physics. Major topics include the physical properties of rocks, the nature and dynamics of the Earth's gravity and magnetic fields, the propagation of waves in the Earth (seismology), and the dynamics of the Earth's crust and deep interior.

Geologists and geophysicists are employed in a wide range of fields, including exploration for and development of natural resources such as petroleum, minerals, and groundwater; environmental science; urban planning; oceanography; and various branches of civil

engineering. Potential employers include private industry, research institutions, universities, and government agencies. An advanced degree is generally necessary for research and development work or teaching.

Both the geology and geophysics programs are built around a core of eight basic Earth science courses taken mostly during the second and third years. The curriculum provides a strong foundation in physics, mathematics, and chemistry. The geophysics program emphasizes the first two. Some students select a geology or geophysics major simply to obtain this broad science base.

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 enter professional work with a baccalaureate degree.

Students must pass all core courses with grade of C or higher.

General Requirements

	Credits
Liberal education requirements including Technical Writing	36

Specific courses required of all geology and geophysics students. These must be taken A-F.

Freshman Year
- Math 1251-1252-1261
- Physics 1251-1252-1253 (should be taken as early as possible; Physics 1252 is a prerequisite for Geo 3201)
- Chem 1051-1052 (should be taken as early as possible; Chem 1051 is a prerequisite for Geo 3401)
- One 1xxx Geo course may be taken for credit for the geology degree.

Sophomore year
- Fall: Geo 3201—Geodynamics I (4 cr)
- Winter: Geo 3202—Geodynamics II (4 cr), Geo 3401—Mineralogy (4 cr)
- Spring: Geo 3301—Geochemical Principles (4 cr), Geo 3402—Petrology (4 cr)

Summer After Sophomore Year
- Geo 3111—Introductory Field Geology (4 cr)

Junior Year
- Fall: Geo 5651—Sedimentology (4 cr)
- Spring: Geo 5201—Structural Geology (4 cr)

Summer After Junior Year
- Geo 5111—Advanced Field Geology (4 cr) or Geo 5112—Field Hydrogeology (4 cr)

Additional Requirements for IT Geology Majors

These courses must be taken A-F, unless only offered S-N. Choose specific courses in consultation with the adviser.

Additional geology core courses, taken in junior year
- Winter: Geo 5101—Geochronology and Stratigraphy (4 cr)
- Spring: Geo 5631—Earth-System: Geosphere/Biosphere Interactions (4 cr)
- Workshops (2 chosen from Geo 5010, 5020, or 5030; 2 cr each, 4 cr total)

Total *12*

Additional cognate sciences totaling at least 32 credits, including
- Math 3251, 3261 (8 cr)
- Chem 5520 or equivalent (4 cr)
- Additional science chosen from math, physics, chemistry, engineering, biological sciences, soil science, geography, or any physical or natural science. No more than 8 credits may be taken at the 1xxx level.

Total *32*

Geology and geophysics electives
- Must be 5xxx level or above, except that Geo 3990 and one 1xxx geology course may also be used.

Total *16*

Free electives 18

Total credits for geology major *182*

Additional Requirements for IT Geophysics Majors

These courses must be taken A-F unless only offered S-N. Choose specific courses in consultation with an adviser.

Additional geophysics core courses, taken in junior year
- Fall: Geo 5505—Solid Earth Geophysics I (4 cr)
- Winter: Geo 5506—Solid Earth Geophysics II (4 cr)
- Workshops (2 chosen from Geo 5010, 5020, or 5030; 2 cr each, 4 cr total)

Total *12*

Additional cognate sciences totaling at least 44 credits, including
- Math 3251, 3252, 3261, 3262 (16 cr)
- Chem 5520 or equivalent (4 cr)
- Physics 1254 plus 4 cr of physics at 3xxx level or higher (8 cr total)
- Additional science chosen from math, physics, chemistry, engineering, biological sciences, soil science, geography, or any physical or natural science. No more than 8 credits may be taken at the 1xxx level.

Total *44*

Geology and geophysics electives
- Must be 5xxx level or above, except that Geo 3990 and one 1xxx geology course may also be used.

Total *16*

Free electives 10

Total credits for geophysics major *186*

Industrial Engineering/ Operations Research

(Department of Mechanical Engineering)

Professional training in industrial engineering is offered through an industrial engineering option available 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 produced by such industrial systems. The industrial engineer studies product designs to adapt them for production, determines an optimal system for necessary operations, selects the most economical production equipment and tooling, and develops effective work methods and measurements.

Students selecting the IEOR option may also apply to the co-op program. For information, see the co-op program description in the mechanical engineering section of this bulletin.

Lower Division
See mechanical engineering lower division requirements.

Upper Division[2,3]

	Credits
Industrial engineering courses	20
IEOR 5010—Introduction to Work Analysis	
IEOR 5020—Engineering Cost Accounting, Analysis and Control	
IEOR 5030—Quality Engineering	
IEOR 5040—Introduction to Operations Research	
IEOR 5254—Design Morphology with Application Mechanical Engineering courses	26
ME 3201—Mechanical Engineering Systems Analysis	
ME 3203—Analysis of Mechanism Systems	
or ME 3205—Engineering System 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 5260—Engineering Materials and Processing	
Advanced Mechanical Engineering Laboratory (2 cr required)	
Electrical engineering courses[1]	
EE 3009—Linear Circuits I[1]	
EE 1400—Circuits Laboratory[1]	
Liberal education electives	16
Coherent Elective Program[2]	24
Technical Writing	4
	95

Graduate Study—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.

[1] *Students not completing the IEOR option will be required to also take EE 3005 and EE 3006.*
[2] *See information about coherent elective programs under Special Programs and obtain the program brochure in 121 Mechanical Engineering.*
[3] *Credit and course requirements are subject to change by faculty action and may affect requirements for graduation.*

Materials Science and Engineering

(Department of Chemical Engineering and Materials Science)

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

The need for materials engineers crosses the boundaries of many industries. In the aircraft industry, for example, materials science and engineering tasks include creating materials that are resistant to fatigue, fracture, corrosion, and heat. Examples in other industries include:

automotive: develop high-strength, heat-resistant materials for low-emission gas turbine engines

chemical: select and develop materials to build chemical reactors that can withstand extremes of temperatures and environment

microelectronics: develop new semiconductor devices for electronic circuitry

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 and nuclear waste

other high-technology areas: create new types of polymers and new polymer processing techniques to meet the needs of a wide range of applications

Based on a foundation of mathematics, physics, and chemistry, the curriculum offers specialized professional courses in electronic materials, physical metallurgy, thermodynamics, polymer engineering, corrosion, and related lab studies.

Degree Requirements—To receive a bachelor of materials science and engineering degree, students must complete 192 credits of coursework for an approved program. These credits include liberal education credits, about 64 credits in basic sciences, and about 92 credits in required and elective advanced science and engineering courses. Elective courses may be chosen to build expertise in a specialty area or to provide a broad and diverse background. Students plan their degree program with a faculty adviser to prepare for professional work or graduate studies. Sample programs are available from faculty advisers or from the department office, 151 Amundson Hall.

The program is accredited by the Engineering Accreditation Commission of ABET.

Transfer Students—Most students who transfer from another campus or school with lower division standing in general engineering have satisfied most course requirements or have equivalent coursework to offer. For specific information, students should write, call, or visit the Department of Chemical Engineering and Materials Science, University of Minnesota, 151 Amundson Hall, 421 Washington Avenue S.E., Minneapolis, MN 55455 (612/625-1313). Students can obtain certification of completion of the lower division requirements when they transfer.

Lower Division

First Year	Credits *f*	*w*	*s*
Math 1251-1252-1261—Calculus I-III	4	4	4
Chem 1051-1052—Chemical Principles I-II	4	4	...
Chem 3301, 3305—Introductory Organic Chemistry with Laboratory	...	...	6
Phys 1251-1252—General Physics	...	4	4
Comp 1011—Writing Practice I	5	...	...
Liberal education electives	4	4	4
	17	16	18

Second Year	Credits *f*	*w*	*s*
Phys 3501—Modern Physics (or Chem 5533—Quantum Physics)	...	4	...
Phys 1253—General Physics	4	...	...
Math 3251-3261-3252	4	4	4
MatS 3400—Introduction to Mechanical Properties	...	...	4
ChEn 3001—Computational Methods	...	2	...
AEM 1015—Statics	4	...	...
AEM 3016—Deformable Body Mechanics	...	4	...
Biol 1009—General Biology	...	...	5
Liberal education electives	4	...	4
	16	14	17

Upper Division

Third Year	Credits *f*	*w*	*s*
MatS 5011-5012-5013—Introduction to Science of Materials, Physical Metallurgy, Electronic Properties	4	4	4
ChEn 5101—Computation	4	...	...
Chem 5534—Chemical Thermodynamics	4	...	...
MatS 5101-5102—Thermodynamics and Kinetics	...	4	4
Comp 3015—Writing About Science *or* Comp 3031—Technical Writing for Engineers	...	4	...
MatS 5200—Microscopy	4	...	...
MatS 5202—X-Ray Analysis	...	4	...
Technical electives	...	...	4
Liberal education electives	...	...	4
	16	16	16

Fourth Year	Credits *f*	*w*	*s*
MatS 5411—Materials Design	...	4	...
MatS 5304—Failure Analysis	...	...	4
MatS 5610—Introduction to Polymers	3	...	...
MatS 5630—Polymer Physical Properties	...	3	...
MatS 5613—Polymer Lab	...	...	2
MatS 5112—Ceramics	4	...	...
MatS 5450—Corrosion	4	...	...
MatS 5820—Thin Film Technology	...	...	3
MatS 5500—Senior Design Project	...	2	2
Technical electives	4	8	4
	15	17	15

Mathematics

The School of Mathematics offers programs leading to the bachelor of science in mathematics (B.S.) degree through the Institute of Technology and the bachelor of arts (B.A.) degree through the College of Liberal Arts. Information about the B.A. program can be found in the *College of Liberal Arts Bulletin.*

The course of study for the B.Math. degree is very flexible and can be adapted to satisfy a wide variety of interests and needs. Programs can focus on preparation for graduate study in mathematics or preparation for secondary school teaching, or can emphasize diverse fields of interest such as applied mathematics, computer science, or actuarial science. Further information about the mathematics program, including information about the programs in actuarial science and secondary mathematics education, is available in 4 Vincent Hall.

Prescribed courses for the math major are listed below. In addition, students must complete certain liberal education requirements that are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.

All courses used to fulfill the requirements listed below must be taken A-F and passed with a grade of C or higher.

Majors must see a mathematics adviser at least once each year. Appointments can be made in 4 Vincent Hall or by phone at (612) 625-4848.

Lower Division Mathematics Requirements

1251 or 1351—One-Variable Differential Calculus
1252 or 1352—One-Variable Integral Calculus
1261 or 1353—Calculus III
3251—Multivariable Differential Calculus
3252—Multivariable Integral Calculus
3261—Differential Equations with Linear Algebra
3262—Sequences, Series, and Foundations

The last four of these courses do not have to be taken in the order listed and some can be taken concurrently. The 12xx courses are considered "traditional" while the 13xx courses are considered "reformed." Admission to the reformed course requires permission of the instructor. Interested students should come to the Math Office (4 Vincent Hall) to make arrangements.

There is also a parallel sequence of honors courses: 1551H-1552H-1553H-3551H-3552H-5553H. These courses must be taken in the order listed and in consecutive quarters. Screening for admission and placement into honors courses is conducted by the IT Honors Office, 136 Lind Hall.

IT math majors must take one course in computer science at the 3xxx level (3113—Programming in C is recommended) and complete a four-part calculus-based physics sequence such as 1251-1252-1253-1254.

Students with credit for one quarter (or semester) of calculus will presumably exempt 1251 and begin with 1252. Students with credit for two quarters of calculus will presumably exempt 1251-1252 and begin with 1261. Students with a full year of calculus may start with 3251 or 3261. Transfer students who have completed a year-long, calculus-based physics course may complete their physics requirement with any 3xxx physics course such as 3601. Other advanced placement students must consult a math adviser, available by appointment in 4 Vincent Hall. When appealing IT credit awards or adviser recommendations, students must provide the director of undergraduate studies with a college bulletin from their former school. Failing that a course outline and/or text may be offered.

Upper Division

186 total credits and 15 math or math-related courses: analysis (3 courses); algebra (3 or 4 courses); depth (3 or 4 courses); technical elective package (3 courses); free math electives (as needed to reach the total of 15).

Analysis—The standard analysis sequence is 5606-5607-5608. Students who want to pursue graduate study may instead take 5612-5613-5614.

Algebra—This requirement may be filled in three ways:
Linear algebra emphasis: 5242-5243-5245-5246
Modern algebra emphasis: 5245-5246-5247
Graduate School track: 5282-5283-5284

Depth—This involves selecting one or two "areas of specialization" from the following list. If one area is selected, then a full three-part sequence must be taken; if two areas are selected, then two two-part sequences must be taken: logic (5162-5163-5164), geometry (5331-5332-5333), topology (5341-5342-5343), differential geometry (5375-5376-5377), algebraic geometry (5381-5382-5383), methods of applied mathematics (5457-5458-5459), industrial mathematics (5463-5464-5465), numerical analysis (5473-5474-5475 or CSci 5301-5302-5304-5305-5306), ordinary differential equations (5521-5522-5523), dynamical systems (5531-5532-5533), partial differential equations (5571-5572-5573), probability (5681-5682-5683), statistics (Stat 5131-5132-5133), combinatorics/graph theory (5701-5702-5703), and actuarial mathematics (5056-5057-5058-5059). Certain other sequences in the *IT Bulletin* may be substituted *with adviser approval.* In particular, the *combined* linear and modern algebra courses (5242-5243-5245-5246-5247) along with number theory (5209) fulfill both algebra and depth.

Technical Elective Package—Three courses of at least 3 credits each, not necessarily in the math department, but constrained by three requirements:

1) Calculus (1251 or equiv) shall be a prerequisite (or a prereq for a prereq).
2) The courses shall be numbered 3xxx or higher.
3) The package shall have a "theme" or "connection," and requires prior math adviser approval.

Free Math Electives—These must be in the math department and numbered 5xxx or higher. Certain math courses labeled "not acceptable as part of a major program" may not be used. Stat 5131-5132-5133 or CSci 5301-5302-5304-5305-5306 may be used. No other courses outside the math department may be offered as free math electives.

Not more than one of Stat 5131, Math 5681, or Math 5679 nor more than one of Math 5512 or Math 5457 may be offered as part of the major program. However, the grouped courses are considered equivalent for purposes of prerequisite and/or depth. The math department will not accept two depth sequences both of which are in numerical analysis (one in math, one in computer science) from the same student.

Specializations

Formal recognition of a subprogram in actuarial science or mathematics education is possible. The student first informs his or her math adviser of intent to specialize. The designated subprogram will then appear on all transcripts provided the following additional requirements are completed:

Actuarial Science

Additional Depth Requirements: Two three-part areas of specialization in statistics and actuarial math. Actuarial math must include 5056; 5059 is recommended. Statistics may consist of either Stat 5131-5132-5133 or Math 5679/Stat 5121-5122 (Stat 5121-5122 may serve as part of the technical elective).

Additional Required Coursework:
Economics: 1104-1105 or 1101-1102-3101
Business: Acct 1050, BFin 3000, and Ins 5100

Mathematics Education

Additional Depth Requirements: An area of specialization in geometry. Two additional courses chosen from Stat 5131-5132, Math 5209-5679-5681-5682-5701-5702-5703. If a second area of specialization is required, the two courses selected from this list must be linked (no more than one of Stat 5131, Math 5679, or Math 5681 may be elected). Any other required free math elective may be taken from the previous list or from 5151-5152-5162-5163-5164-5341-5342-5473-5568.

Note: Some of the 186 credits required for this program may be taken in the College of Education and Human Development and the entire technical elective package may be taken in mathematics education.

Mechanical Engineering

Mechanical engineering is involved in most technological activities of society and dominates many, including automotive, transportation and materials handling, environmental and pollution control systems, refrigeration and cryogenics, design of nuclear and conventional power systems, automation, system dynamics and control, computer-aided design and manufacturing, and the production of machinery and consumer products. The mechanical engineer may be engaged in design, development, research, testing, manufacturing, administration, marketing, consulting, or education.

The program provides preparation for a career in mechanical engineering or for graduate work. A strong background in the basic sciences of mathematics, physics, and chemistry is balanced with courses in engineering science and applied engineering. The use of computers as an engineering tool is emphasized throughout much of the course work. 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 four-year curriculum requires 194 quarter credits and leads to the bachelor of mechanical engineering (B.M.E.) degree. The program is accredited by the Engineering Accreditation Commission of ABET.

Elective Programs—Various coherent elective programs are available in mechanical engineering that provide further in-depth study in designated areas of the profession. In addition, several cross-disciplinary programs involve work in mechanical engineering and other departments.

A coherent technical elective program of about 24 credits is required. A list of suggested programs is available in the Advising and Information Center, 121 Mechanical Engineering. Areas of specialization include system design and control, manufacturing engineering, computer-aided design, thermodynamics and heat transfer, environmental engineering, power and propulsion, industrial engineering/operations research, materials engineering, bioengineering, and a mechanical-electrical engineering emphasis.

Because the total elective choice is considerable, students must consult an adviser to formulate an effective program that meets both their needs and degree requirements.

Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). A total of seven courses (28 credits) are required. Students must satisfy both the diversified core and designated theme requirements.

Graduate Study—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. In addition, master's degree programs in mechanical engineering (M.M.E.) and industrial engineering (M.I.E.) are offered by the Institute of Technology through the Graduate School. Information about these programs is available in the Student Advising and Information Center, 121 Mechanical Engineering (612/625-2009, e-mail gradinfo@me.umn.edu).

Special Programs—The *Coherent Elective program* in mechanical engineering offers students the opportunity to pursue interdisciplinary study involving several departments as well as work in the community and industry. Information about this program is available in 121 Mechanical Engineering (612/625-5842, e-mail u-gradinfo@me.umn.edu).

A brief description of two of the interdisciplinary study opportunities is presented below:

Bioengineering—Project work in bioengineering is available. In addition, students can combine elective work in selected physics, chemical engineering, electrical engineering, fluid flow, biomedical engineering, and agricultural engineering courses to prepare for work or graduate study in bioengineering. Students preparing for work in bioengineering may also plan their studies to meet some of the entrance requirements for medical school.

Environmental Engineering—The department offers work in environmental engineering with emphasis on air pollution, energy use, and emission studies. The mechanical engineering staff offers courses in particle technology, air quality, contaminant control, thermal environmental engineering, and exhaust emission analysis. 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.

The *Co-op Program* is available during the last two 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 assignments that alternate with quarters of University studies. A B.M.E. degree is awarded upon satisfactory completion of the required mechanical engineering curriculum work as well as four quarters of industrial assignment. Students should contact the co-op program office for more information, 142 Mechanical Engineering (612/625-5326, e-mail co-opinfo@me.umn.edu).

The *Industrial Engineering/Operations Research program* provides engineering training with specialization in industrial engineering. Students in the program may also apply to the co-op program. For more information, see the industrial engineering/operations research program description.

By careful selection of liberal education and coherent program electives, the student can prepare, in part, for *subsequent study* in other fields including business, law, and medicine.

Course Requirements[1]—The lower division program includes coursework in basic and engineering science preparatory for studies in the upper division. The upper division program includes coursework in additional engineering science and applied engineering subjects such as laboratory and design. Further details and information about alternate course selections, coherent elective programs, areas of specialization, and changes in course or credit requirements, as well as supplemental department brochures, are available in 121 Mechanical Engineering (612/625-5842).

Lower Division[1,2]

	Credits
Comp 1011—Writing Practice I	5
Math 1251, 1252, 1261, 3261, 3251, ME 3900—Differential Calculus, Integral Calculus, Algebra and Geometry of Euclidean Space, Differential Equations with Linear Algebra, Multivariable Differential Calculus, Engineering Statistics	24
Phys 1251-1252-1253—General Physics	12
Chem 1051-1052, MatS 3400 and additional science electives as specified by the department	16
Introduction to Engineering	9
ME 1025—Graphics, CSci 3101—Introduction to Computer Applications for Scientists and Engineers, ME 1001—Introduction to Mechanical Engineering (optional)	
Engineering Science	24
AEM 1015—Elements: Statics, AEM 3016—Deformable Body Mechanics, AEM 3036—Dynamics, CE 3400 or AEM 3200—Fluid Mechanics, ME 3020—Mechanical Engineering Computation, IEOR 3000—Industrial Engineering	
Liberal education electives (about)	12
	101-102

Upper Division[1,2,3]

	Credits
Basic Engineering Program	41
ME 3301, 3303, 5342—Thermal Engineering ME 3201, 3203, 3205—Mechanical Engineering Systems and Design EE 3009, 3005, 3006—Linear Circuits I; Electronic Circuits and Systems; Circuits/Electronics Lab ME 5260—Material Engineering and Processing ME 5254—Design Morphology with	
Application Laboratory Program	8
ME 3701-3702—Basic Measurements Laboratory I-II Advanced Mechanical Engineering Laboratory (4 cr required)	
Liberal education electives (sufficient to complete liberal education requirements)	16
Coherent Elective Program[3]	24
Technical Writing	4
	93

[1] *For a complete description of the lower division program, alternate course selections, and suggested scheduling, students should obtain the curriculum brochure in 121 Mechanical Engineering.*

[2] *Credit and course requirements are subject to change by faculty action and may affect requirements for graduation.*

[3] *See information about coherent elective programs under the heading Special Programs and obtain the program brochure in 121 Mechanical Engineering.*

Physics

(School of Physics and Astronomy)

Physics is concerned with the fundamental properties and laws of all forms of matter, nonliving and living. Experimental and theoretical investigations are combined to formulate mathematical relationships that describe and predict the behavior of the physical and biological world.

Some students may seek employment after obtaining the bachelor's degree, often in an industrial or government laboratory. Others may pursue further study in physics, engineering, biophysics, medicine, education, law, or business. Information about physics programs is available in 148 Tate Laboratory of Physics.

The required courses provide a broad foundation in experimental and theoretical physics. These courses form a minimum program. Students preparing for a specific career path may want to take more physics courses than required. Electives chosen from engineering, biophysics, or mathematics can help prepare students for a career or for graduate study in a specific area. Students with a well chosen and successful bachelor's degree in physics can go on to graduate study in physics or other fields. Students should consult an adviser or the undergraduate office to help formulate objectives for undergraduate study.

Students interested in a graduate program should choose undergraduate electives related to that program, in consultation with their adviser.

A total of at least 180 credits is required for the degree. This minimum must include 106 credits of required physics and mathematics, at least 36 credits of liberal education courses, and at least 33 credits of technical electives. (Students should choose these electives carefully; a suggested list is given below.)

Chemical Principles I-II (Chemistry 1051-1052) is recommended as a technical elective, but is not required.

Liberal education requirements are the same for all students on the Twin Cities campus (see page 24 in this bulletin). Students must satisfy both the diversified core and designated theme requirements.

A required advanced English composition course and any required language courses can be included in the liberal education total. Students not exempt from freshman writing practice can include credits for this course in their liberal education total as well. Students should consult the IT Student Affairs Office concerning exemption from foreign language requirements. Details on liberal education requirements and acceptable course list can be obtained from the IT Student Affairs Office or from 148 Tate Laboratory of Physics.

Those with broader liberal education interests should consider the CLA physics major as an option. The CLA degree may be more suitable for some students and can lead, with a well chosen program, equally well to graduate study in physics.

Physics majors must take all required physics and mathematics courses A-F and must earn a grade of C or better in all of these courses, except those offered S-N only. Only students with grades of B or better in the freshman physics courses can generally expect to succeed in the major.

Where available, honors courses can always be substituted for the regular course requirement. For exceptionally able students who also intend to go on to graduate school, certain graduate courses can be substituted for the relevant undergraduate course.

General Requirements

(based on 180 credits)

	Credits
Physics	
Phys 1251-1252-1253-1254—Comprehensive Introductory Physics or Honor Physics	16
Phys 3512-3513—Quantum Physics I-II	6
Phys 3515-3516—Quantum Physics Lab	4
Phys 3601—Special Relativity	3
Phys 5021-5022—Introduction to Analytic Mechanics	8
Phys 5023-5024—Introduction to Electric and Magnetic Fields	8
Phys 5101-5102—Quantum Mechanics	8
Phys 5121-5122-5123—Methods of Experimental Physics	13
Phys 5201—Thermal and Statistical Mechanics	4
Phys 5xxx—Elective	4
Mathematics	
Math 1251-1252—Calculus I-II	8
Math 1261—Algebra and Geometry of Euclidean Space	4
Math 3251-3252—Multivariable Differential and Integral Calculus	8
Math 3261—Differential Equations	4
Math 5xxx—Electives	8
Technical electives (see list below)	
From IT courses or other science programs, to total at least 33 credits	33-38
Liberal education courses	
Advanced English Composition	4
Other courses to total at least 36 credits in conformity with IT requirements	32-37
	180

Sample Program

(about 16 credits per quarter)

		Credits	
First Year	*f*	*w*	*s*
Phys 1251-1252-1253	4	4	4
Math 1251-1252-1261	4	4	4
Electives	8	8	8
Liberal education			
Chemical Principles I-II (if desired)			
Writing Practice (if required)			
Foreign language (if required)			
Second Year	*f*	*w*	*s*
Phys 1254, 3512-3513	4	3	3
Phys 3515-3516	...	2	2
Phys 3601	3	...	...
Math 3251-3252-3261	4	4	4
Liberal education electives	4	6	6
Third Year	*f*	*w*	*s*
Phys 5021-5022	4	4	...
Phys 5023	...	...	4
Phys 5121-5122-5123	5	4	4
Math 5xxx	4	4	...
Technical electives	4	4	8
Fourth Year	*f*	*w*	*s*
Phys 5024	4	...	...
Phys 5101-5102	4	4	...
Phys 5201 or equivalent	...	4	...
Physics 5xxx elective	...	...	4
Technical electives	8	8	12

Technical Electives—The curriculum includes a minimum of 33 credits of technical electives. Mathematics, chemistry, engineering, biophysics, and other areas may be of interest. The biological science liberal education requirement can also count as a technical elective. Many students will want to take electives in physics or allied areas, for which a partial list follows:

Ast 3051—Introduction to Astrophysics
Ast 5161-5162—Computational Methods in the Physical Sciences
Ast 5165—Cosmology
Phys 5031-5032—Topics in Mathematical Physics
Phys 5202—Introduction to Thermal and Statistical Physics
Phys 5211—Introduction to Solid-State Physics
Phys 5231-5232-5233—Introduction to Solid-State Physics for Engineers
Phys 5301—Introduction to Nuclear Physics
Phys 5371—Introduction to Elementary Particle Physics
Phys 5401—Introduction to Problems in Space Physics
Phys 5551-5552-5553—Topics in Physics for Biology and Medicine

Phys 5461—Physics and Chemistry of the Earth's Upper Atmosphere
Phys 5801—Modern Optics
Phys 5805—Contemporary Optics
Phys 5924-5925—History of Physics

Students interested in engineering disciplines may want to consider appropriate electives. There are many possibilities and a partial list follows:

Chem 1051-1052—Chemical Principles I-II
Chem 3301-3302—Elementary Organic Chemistry I-II
Chem 5534—Chemical Thermodynamics
Chem 5535—Statistical Mechanics, Reaction Kinetics
ChemE 5101-5102—Principles of Chemical Engineering
ChemE 5201—Thermodynamics and Materials States
EE 3351—Introduction to Logic Design
EE 5571-5572—VLSI Design
EE 5630—Contemporary Optics
CSci 3113—Introduction to Programming in C
CSci 3321-3322—Algorithms and Data Structures I-II
CSci 5107—Introduction to Computer Graphics
CSci 5151—Introduction to Parallel Computing
MatS 3600H—Honors Introduction to Materials Science
MatS 5012—Introduction to Dislocations
MatS 5101—Thermodynamics of Solids

Students interested in biological physics may want to consider the following elective possibilities:

Phys 5551-5552-5553—Topics in Physics for Biology and Medicine
BioC 3001—Elementary Biological Chemistry
BioC 5002—Biochemistry Topics
Biol 1009—General Biology
BMEn 5001-5002—Biomaterials I-II
BPhy 5156—Biophysics
PPhy 5171—Physics of Nuclear Medicine

Students interested in business school may want to choose electives in economics, statistics, and computer programming.

The above elective possibilities should be used by students as a starting point for formulating a concrete plan for their elective choices. Prerequisites have not been considered and in many cases other courses may be of equal or greater interest and importance to the student. Consult with your adviser to select acceptable electives.

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 government 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 four-year curriculum leading to the bachelor of science in statistics (B.S.) degree. The school 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 of 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 with the director of undergraduate studies in 270 Vincent Hall.

Lower Division

	Credits
Calculus of a Single Variable	
Math 1251-1252-1261	12
Math 3251-3252	8
Elements of Computer Programming	
CSci 3101 or 3102	4
Physics and Chemistry	
Phys 1251-1252-1253	12
Chem 1001 or 1051	4
Statistics	
Stat 3091-3012	8

Upper Division

	Credits
Stat 5131-5132-5133—Theory	12
Stat 5302—Applied Regression	5
Statistics electives—12 credits chosen from:	
Stat 5091—Statistical Methods for Quality Improvement	4
Stat 5201—Sampling Methodology in Finite Populations	4
Stat 5301—Designing Experiments	5
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 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 3000—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 5682-5683—Probability	8

Course Descriptions

Symbols—The following symbols are used throughout the course descriptions:

* ..... Courses in which graduate students may prepare Plan B projects.

, ... The comma, used in prerequisite listings, means "and."

† ..... All courses preceding this symbol must be completed before credit will be granted for any quarter of the sequence.

§ ..... Credit will not be granted if credit has been received for the course listed after this symbol.

¶ ..... Concurrent registration is required (or allowed) in the course listed after this symbol.

..... Approval of the instructor is required for registration.

Δ ..... Approval of the department offering the course is required for registration.

❑ ..... Approval of the college offering the course is required for registration.

H ..... Honors course.

f,w,s,su,CEE ..... Following a course number indicate fall, winter, spring, summer, or Continuing Education and Extension.

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 in the same department as the course being described.

Special Interest Courses for IT Students (IofT)

IofT 1222. INTRODUCTION TO CAREERS IN SCIENCE AND ENGINEERING. (2 cr; prereq IT student or Δ; 2 hrs per wk; S-N only)
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.

IofT 3311. DEVELOPING EFFECTIVE JOB SEARCH SKILLS. (1 cr; prereq jr or sr or IT grad student)
Presentations by employers and placement staff on writing resumes and letters, identifying and contacting employers, interviewing, using the placement office, and evaluating job offers.

IofT 5101. COMMUNICATION IN SCIENCE AND TECHNOLOGY. (1 cr)
Informal and formal communication. The publication process. Editors and reviewers. Post-publication assessment. Acceptance as knowledge. Electronic communication. The electronic future. Includes a lab in database searching.

Aerospace Engineering and Mechanics (AEM)

AEM 1001f. AEROSPACE ENGINEERING ORIENTATION. (1 cr; prereq IT fr or soph; S-N only)
Fundamentals of aerospace engineering practice presented by professional engineers and members of the faculty.

AEM 1015f,w,s. STATICS. (4 cr; prereq IT student, Phys 1251 or equiv, Math 1261)
Force and moment vectors; resultants. Principles of statics. Applications to simple trusses, frames, and machines. Distributed loads. Hydrostatics. Properties of areas. Laws of friction.

AEM 3005f. INTRODUCTION TO FLIGHT. (4 cr, §1005; prereq IT student, Math 1252 or equiv, Phys 1252 or equiv)
Subsonic aerodynamics; standard atmospheric properties; generation of lift and drag; airfoils and finite wings; elements of airplane performance and stability; atmospheric flight mechanics and computer modeling of flight paths; design of a glider; determination of lift and drag from glider experiments.

AEM 3009w. BASIC GROUND SCHOOL FOR PRIVATE PILOTS. (5 cr; CEE only)
Theory of flight, aircraft performance, aircraft systems and engine operation, flight instruments, and meteorology. Federal Aviation Regulations, cross-country navigation, and radio navigation aids. Prepares the student pilot for the Federal Aviation Administration's Private Pilot written test and the oral questioning used during the Private Pilot practical test.

AEM 3016f,w,s. DEFORMABLE BODY MECHANICS. (4 cr; prereq IT student, 1015, ¶Math 3261 or equiv)
Uniaxial loading and deformation. Stress and strain at a point. Forces and moments. Material behavior; linear elasticity. Torsion. Bending of beams of symmetrical section.

AEM 3036f,w,s. DYNAMICS. (4 cr; prereq IT student, 1015, ¶Math 3261 or equiv)
Review of particle dynamics. Mechanical systems and the rigid-body model. Kinematics and dynamics of plane systems.

AEM 3200f,w. INTRODUCTION TO ENGINEERING FLUID MECHANICS. (4 cr; prereq IT student, 1015, Math 3261 or equiv, Phys 1251 or equiv)
The flow of viscous incompressible fluids; fluid statics, Bernoulli flow, momentum conservation, laminar and turbulent pipe flow, laminar and turbulent boundary layers.

AEM 3281Hs. INTRODUCTION TO LINEAR SYSTEMS. (4 cr, selection for IT honors program or consent of IT Honors Office)
Mathematical modeling of mechanical, hydraulic, and electromechanical systems; Laplace transforms, transfer functions, block diagrams, Bode graphs, time response of free and forced systems, numerical methods, frequency response, elementary concepts in feedback control.

AEM 3401f. INTRODUCTION TO DYNAMICAL SYSTEMS. (4 cr, §ME 3201; prereq IT student, 3036)
Mathematical modeling of mechanical, hydraulic, and electromechanical systems; Laplace transforms, transfer functions and block diagrams, time response of free and forced systems, elementary concepts in feedback control, frequency response.

AEM 5001su. WORKSHOP: ELEMENTARY AND SECONDARY TEACHERS. (4 cr; prereq educ major, in-service teacher [documentation required], Δ; limited to 30 students)
Lectures, film reviews, construction and demonstration of classroom aids, involvement with the NASA spacemobile, flight experience, and field trips covering such topics as satellites and probes, model rocketry including a launch, astronaut in space, principles of flight, conventional aircraft, space age education tools. Visits to local aerospace facility and to major aerospace installation in the country (subject to availability of airlift).

AEM 5002su. ADVANCED AEROSPACE WORKSHOP. (4 cr; prereq educ major, in-service secondary teacher in math or science or aerospace [documentation required] or 5001 or #, Δ)
Advanced workshop for secondary math, science, and aerospace teachers. Uses contemporary NASA design projects to provide new teaching tools to stimulate student interest in math and physics.

AEM 5200f. KINEMATICS AND DYNAMICS OF FLUID FLOW. (4 cr; prereq upper div IT or grad student, 3036, ¶Math 3252)
First course in fluid mechanics. Includes stress and strain rate descriptions, fluid statics, use of differential and finite control volume analysis with continuity, momentum and energy equations, Bernoulli and Euler equations, introduction to Navier-Stokes equations, vorticity, potential flow.

AEM 5202s. VISCOUS FLOW. (4 cr; prereq upper div IT, 5200)
Incompressible viscous flow using Navier-Stokes equations. Dimensional analysis; one-dimensional exact solutions; pipe flow; laminar and turbulent boundary layers, wakes, and jets; momentum integral; pressure gradients and separation; introduction to turbulence; Reynolds stresses.

AEM 5204f. SHOCK WAVES AND COMPRESSIBLE FLUID FLOW. (4 cr; prereq upper div IT, 5200, ME 3301)
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.

AEM 5205. AEROSPACE PROPULSION. (4 cr; prereq upper div IT, 5205, ME 3301)
Fundamentals of propulsion. Performance parameters. Thermodynamic cycles. Performance analysis of flight propulsion systems: turbojets, turbofans, ramjets, rockets, propellers.

AEM 5206w. AERODYNAMICS OF LIFTING SURFACES. (4 cr; prereq upper div IT, 5200, CSci 3101)
Pressure distributions, forces, and moments on airfoils and wings of finite span. Analysis of potential flow by thin airfoil theory, lifting line theory, and panel methods. Viscous effects and their relation to design variables.

AEM 5240. RAREFIED GAS DYNAMICS. (4 cr; prereq IT or grad student, 5201 or Δ)
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.

AEM 5243. ADVANCED AERODYNAMICS. (4 cr; prereq 5206)
Interaction between pressure distribution and boundary-layer growth on air foils of arbitrary shape. Inviscid flow past non-planar wings of specified planform.

AEM 5244w. HYPERSONIC AERODYNAMICS. (4 cr; prereq upper div IT or grad student, 5204)
Importance and properties of hypersonic flow. Hypersonic shock and expansion-wave relations. Local surface inclination methods. Approximate and exact methods for hypersonic inviscid flowfields. Viscous flow: boundary layers, aerodynamic heating, hypersonic viscous interactions, computational methods. Hypersonic propulsion and vehicle design.

AEM 5250s. COMPUTATIONAL FLUID MECHANICS. (4 cr; prereq IT or grad student, FORTRAN, 5200)
Introduction to computational fluid mechanics with emphasis on finite element method; fundamentals of spatial discretization and numerical time-integration. Introduction to engineering and scientific computing environment and large-scale computing.

AEM 5300w. FLIGHT MECHANICS. (4 cr; prereq IT or grad student, 3005 or 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.

AEM 5319s. DYNAMICS AND CONTROL OF AEROSPACE VEHICLES. (4 cr; prereq IT or grad student, 3401, 5300 or #)
Reference frames, kinematics and equations of motion. Forces and moments, trim, linearization and dynamic response characteristics for aircraft and spacecraft. Handling qualities. Aircraft stability derivatives, phugoid, short period, spiral, roll subsidence, and dutch roll modes, approximations and transfer functions.

AEM 5321w. AUTOMATIC FLIGHT CONTROL SYSTEMS. (4 cr; prereq 3401 or equiv)
Analysis and synthesis of automatic flight control systems for aerospace vehicles, longitudinal and lateral autopilots, stability augmentation systems, design by root locus, Nyquist and Bode techniques. Introduction to state space formulation.

AEM 5329. FUNDAMENTALS OF AEROSPACE VEHICLE DESIGN. (4 cr; prereq AEM sr, 5300 or #)
Design process, design requirements, mission analysis, tradeoffs, sizing of vehicle components, weight estimates, performance, propulsion systems, weight and balance, stability and control, cost, ground and flight testing, compliance and certification. Students prepare a conceptual design of an aerospace vehicle and prepare a written report and oral presentation.

AEM 5330w, 5331s. DESIGN OF AEROSPACE ELEMENTS AND SYSTEMS. (4 cr per qtr; prereq 4th-yr engineering major or Δ)
Group and individual design projects.

AEM 5359w. DECELERATION OF AEROSPACE CRAFT. (4 cr; prereq IT student, 3036, 5200)
Parachutes and other aerodynamic decelerators. Types, characteristics and applications, drag coefficients and steady descent, stability, deployment and opening forces, apparent mass effects, trajectory analysis, stress analysis, engineering properties of textile materials. Individual design projects.

AEM 5370w. 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.

AEM 5410f. INTRODUCTION TO ASTRODYNAMICS. (4 cr; prereq 3036)
Fundamental concepts of the two-body problem. Celestial coordinates, orbital elements. Orbit maneuvers and introduction to the three-body problem.

AEM 5435s. INTRODUCTION TO RANDOM VIBRATIONS. (4 cr; prereq 3401 or ME 3201)
Fundamental concepts of probability theory, random variables, and statistical averages. Elements of stochastic system theory. Response of one- and two-degree-of-freedom mechanical systems to nondeterministic inputs. Fatigue failure criteria, acoustic excitation.

AEM 5438f. 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, and applications, multiple-degree-of-freedom dynamical systems.

AEM 5515w. AEROSPACE STRUCTURES I. (4 cr; prereq IT student, 3016)
Advanced strength of materials analysis of elastic structures with aerospace applications. Failure modes and criteria, buckling, matrix methods for analysis, plane truss design. Energy and Castigliano methods for statically indeterminate structures. Torsion and bending of asymmetrical thin-walled open and closed sections.

AEM 5516s. AEROSPACE STRUCTURES II. (4 cr; prereq IT student, grade of C or better in 5515 or Δ)
Use of prepared computer programs for both microcomputers and main frame computers to solve moderately sized problems of analysis and design of trusses, plane frames, torsion, plane stress, and combination structures; elastic and inelastic analysis; use of symmetry and superposition to extend power of prepared programs; basis of the finite element methods used.

AEM 5518w. MECHANICS OF COMPOSITE MATERIALS. (4 cr; prereq upper div IT student, 3016)
Analysis, design, and applications of laminated and chopped fiber reinforced composites. Micro- and macro-mechanical analysis of elastic constants, failure and environmental degradation.

AEM 5580f. MECHANICS AND THERMODYNAMICS OF SOLIDS. (4 cr; prereq upper div IT or grad student, Math 3251)
Nonlinear continuum mechanics and thermodynamics in one dimension. Kinematics; mass, momentum, energy, and entropy; balance equations and jump conditions. Linear and nonlinear elastic constitutive equations. Applications drawn from wave propagation, stability, thermodynamics and Gibbs thermostatics, fracture mechanics, plasticity, and viscoelasticity.

AEM 5581w. THERMODYNAMICS AND MECHANICS OF SOLIDS. (4 cr; prereq upper div IT or grad student, Math 3251)
Thermodynamics and mechanics of solids. Basic ideas of energy, power, heating, entropy, and stability; their use in formulating nonlinear constitutive equations and designing experiments. Analysis of shear induced phase transitions and other instabilities. Other topics may include shock waves, solid state engines, and other devices.

AEM 5630f. AEROMECHANICS LABORATORY I: FLUID MECHANICS. (4 cr; prereq upper div IT, 3016, 3036, 5200)
Experimental methods and design in fluid dynamics. Wind tunnel and water channel experiments involving flow visualization, pressure, velocity, and force measurement techniques. Computerized data acquisition, dimensional analysis, error analysis, data reduction methods. Written and oral lab reports required.

AEM 5631w. AEROMECHANICS LABORATORY II: SOLIDS AND STRUCTURES. (4 cr; prereq upper div IT, 3016, 3036, 5200)
Experimental determination of stresses, strains, and displacements that occur in solids and structures. Error analysis, computerized data acquisition and analysis, strain gauges, photo-elasticity, material behavior, stress concentrations, composite materials. Written and oral lab reports required.

AEM 5632s. AEROMECHANICS LABORATORY III: DYNAMICS AND CONTROLS. (4 cr; prereq upper div IT, 3016, 3036, 5200)
Experimental determination of dynamic response of systems and design and implementation of feedback controllers. Actuators and sensors for dynamic systems, digital signal processing, fast Fourier transforms. Written and oral lab reports required.

AEM 5650s. AEROELASTICITY. (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.

AEM 5687f. INTRODUCTION TO ACOUSTICS AND ENVIRONMENTAL NOISE. (4 cr; prereq upper div IT or grad student, Phys 1253 or equiv, Math 3361 or equiv)
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, lab experience in sound and noise measurements and noise control techniques.

AEM 5800, 5801, 5802f,w,s. PROBLEMS IN MECHANICS AND MATERIALS. (1-4 cr per qtr; prereq Δ)
Topics of current interest. Individual projects with consent of faculty sponsor.

AEM 5810, 5811, 5812f,w,s. PROBLEMS IN FLUID MECHANICS. (1-4 cr per qtr; prereq Δ)
Topics of current interest. Individual projects with consent of faculty sponsor.

AEM 5821H, 5822H. AEROSPACE ENGINEERING AND MECHANICS HONORS THESIS I-II. (4 cr; prereq upper div AEM honors student, #)
Individual projects under the direction of a member of the AEM faculty.

AEM 5838, 5839su. SUMMER ENGINEERING EMPLOYMENT. (1-4 cr per qtr; prereq completion of 3rd yr, Δ)
Written report based on summer work in an engineering field (not less than 360 hours per summer).

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

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

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

AEM 8201, 8202, 8203. FLUID MECHANICS I-III

AEM 8209. ROTATING FLUIDS

AEM 8216, 8217. THEORY OF TURBULENCE I-II

AEM 8219. COMPUTERS IN THE LABORATORY

AEM 8220. RHEOLOGICAL FLUID MECHANICS I

AEM 8221. RHEOLOGICAL FLUID MECHANICS II

AEM 8232. PHYSICAL GAS DYNAMICS

AEM 8240. PERTURBATION METHODS IN FLUID MECHANICS

AEM 8250. COMPUTATIONAL AERODYNAMICS

AEM 8260. NONLINEAR WAVES IN MECHANICS I

AEM 8410. ADVANCED DYNAMICS

AEM 8411. LINEAR SYSTEMS

AEM 8412. NONLINEAR SYSTEMS

AEM 8413. ADVANCED NONLINEAR SYSTEMS

AEM 8414. HAMILTONIAN SYSTEMS ON MANIFOLDS

AEM 8420. TRAJECTORY OPTIMIZATION TECHNIQUES

AEM 8421. MODERN CONTROL THEORY FOR AEROSPACE SYSTEMS

AEM 8422. ROBUST MULTIVARIABLE CONTROL DESIGN

AEM 8425. ADVANCED TOPICS IN AEROSPACE GUIDANCE AND CONTROL

AEM 8501, 8502, 8503. RESEARCH SEMINAR IN THE MECHANICS OF MATERIALS

AEM 8510. CONTINUUM MECHANICS I

AEM 8511, 8512. CONTINUUM MECHANICS II-III

AEM 8522. THEORY OF PLASTICITY

AEM 8540. THEORY OF VISCOELASTICITY

AEM 8570. FRACTURE MECHANICS

AEM 8585. ADVANCED TOPICS IN CONTINUUM MECHANICS

AEM 8589. MECHANICS OF CRYSTALLINE SOLIDS

AEM 8594. ELASTOSTATICS I

AEM 8595. ELASTOSTATICS II

AEM 8596. ELASTODYNAMICS

AEM 8601. FINITE ELEMENT METHODS IN COMPUTATIONAL MECHANICS

AEM 8602. FINITE ELEMENT METHODS IN COMPUTATIONAL FLUID MECHANICS

AEM 8777. THESIS CREDITS: MASTERS

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

AEM 8810, 8811, 8812. SELECTED TOPICS IN FLUID MECHANICS

AEM 8820, 8821, 8822. SELECTED TOPICS IN DYNAMICAL SYSTEMS AND CONTROLS

AEM 8880. THESIS CREDITS: DOCTORAL

AEM 8888. PLAN B PROJECT

Agricultural Engineering (AgEn)

AgEn 1060f,s. AGRICULTURAL ENGINEERING ORIENTATION. (1 cr; S-N only; 2 hrs per wk)
Introduction to the agricultural engineering profession through lectures, readings, discussions, and presentations by faculty, practicing engineers, and fellow students. Areas of specialization, the environment, safety, ethics, professionalism. Internships, employment opportunities, advanced studies.

AgEn 3031s. COMPUTATIONS IN AGRICULTURAL ENGINEERING. (4 cr; prereq IT student, computer programming, Math 3261 or ¶Math 3261; 3 lect, 2 rec hrs per wk)
Computational techniques applied to agricultural engineering problems: spreadsheets, elementary numerical methods, computer drafting, engineering economics, selected engineering software. Effective presentation of quantitative and graphical information.

AgEn 3052f. ENGINEERING PRINCIPLES OF SOIL-WATER-PLANT SYSTEMS. (4 cr; prereq IT student, some biology background, AEM 3016 or ¶AEM 3016; 3 lect, 3 lab hrs per wk)
Mechanical and hydraulic properties of soil; moisture relations; strength parameters for structural and mechanical design. Soil-machine action in tillage and traction. Energy and water balance in the soil-water-plant system. Plant structure and growth. Engineering and management requirements.

AgEn 3150s. BIOLOGY FOR ENGINEERING. (4 cr; prereq Biol 1009, ME 3301 or ¶ME 3301 or #)
Understanding biology in terms of mathematics, chemical reactions, transport phenomena, material science, mechanics, and electronics. Applications to engineering.

AgEn 3970f,w,s. DIRECTED STUDIES IN AGRICULTURAL ENGINEERING. (Cr ar; prereq #)
Independent study of topic(s) involving physical principles as applied to agricultural production and land resources.

AgEn 5050f,w,s. INTERN REPORTS. (2 cr per qtr; prereq IT student, #)
Student exposure to engineering practice through an intern program. Engineering reports on work assignments are reviewed by faculty and coordinated with industry advisers.

AgEn 5070s. AUTOMATIC CONTROL AND INSTRUMENTATION. (4 cr; prereq upper div IT or forest products major or grad, CE 3400 or equiv; 3 lect, 2 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.

AgEn 5072s. FINITE ELEMENT METHOD: FUNDAMENTALS AND APPLICATIONS. (4 cr; prereq upper div IT or grad IT major, 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.

AgEn 5074f. MICROCOMPUTER INTERFACING. (4 cr; prereq upper div IT or grad IT major, AgET 3030 or CSci 3101 or CSci 3102; 2 lect, 4 lab hrs per wk)
Introduction to digital components, integrated circuits and microcomputers. Interfacing of microcomputers for data acquisition and control.

AgEn 5140w. THERMAL PROCESSES FOR FOOD. (4 cr; prereq upper div IT or grad IT major, heat transfer; 3 lect, 3 lab hrs per wk)
Engineering principles of thermal processing of food, pasteurization, microwave heating, heat exchange, evaporation, refrigeration and freezing. Process design and evaluation.

AgEn 5191-5192f,w,s. SPECIAL PROBLEMS IN AGRICULTURAL ENGINEERING. (2-5 cr per qtr; prereq #)
Individual study project at an advanced level involving application of engineering principles to a specific problem.

AgEn 5350f. AGRICULTURAL MACHINERY AND TERRAMECHANICS. (4 cr; prereq upper div IT or grad IT major, AEM 3016, AEM 3036; 3 lect, 3 lab hrs per wk)
Engineering principles governing the performance of machinery used in agriculture. Emphasis on soil-machine interaction (traction and tillage), off-road vehicle dynamics, operator-machine interaction, drive-line design, power unit selection, and duty cycle analysis.

AgEn 5540f. WATERSHED ENGINEERING. (4 cr; prereq upper div IT or grad IT major, 3052 or CE 3300, CE 3400; 3 lect, 3 lab hrs per wk)
Application of engineering principles to the management of surface runoff and soil water in agricultural, range and urban lands. Designing facilities for control of surface runoff to mitigate problems of flooding and degradation of surface water quality.

AgEn 5550w. WATER MANAGEMENT ENGINEERING. (4 cr; prereq upper div IT or grad IT major, 3052 or CE 3300, CE 3400; 3 lect, 3 lab hrs per wk)
Application of engineering principles to the management of water for production and environmental protection in agricultural systems. Design of facilities to irrigate and drain croplands and to enhance water quality.

AgEn 5560w. MECHANICS OF FLOW IN THE UNSATURATED ZONE. (4 cr; prereq upper div IT or grad IT or College of Agricultural, Food, and Environmental Sciences grad student, Math 3261, Soil 5232 or #; 2 lect hrs per wk)
Fluid retention and transmission properties of unsaturated porous media. Equations of mass conservation and Darcy's law for unsaturated porous media. Simultaneous flow of immiscible fluids. Analytical, finite difference and finite element solutions to the governing equations.

AgEn 5745f. VENTILATING SYSTEMS FOR INDOOR AIR QUALITY. (4 cr; prereq upper div IT or grad IT major, ME 3301, CE 3400 or AEM 3200; 4 lect hrs per wk)
Impact of indoor air quality on humans, animals, and plants. Contaminant sources. Ventilating processes, systems, control strategies, and equipment for indoor air quality control. Case studies from residential, commercial and agricultural systems.

AgEn 5751f. BIOCHEMICAL ENGINEERING I. (3 cr, §ChEn 5751; prereq AgEn major or grad student or ChEn major or #; 3 lect hrs per wk)
Applications of material and energy balances and concepts from thermodynamics, kinetics, and transport phenomena to cellular and enzyme systems.

AgEn 5891f. SENIOR DESIGN I. (1 cr; prereq upper div IT, sr status or #; 5891-5892†; 2 rec hrs per wk)
Introduction to design concepts. Case studies involving engineering design. Development of proposal for a senior design project (individual or group) to be completed in 5892. Oral presentation of written proposal.

AgEn 5892w. SENIOR DESIGN II. (4 cr; prereq 5891; 5891-5892†; 6 rec hrs per wk)
Completion of design project started in 5891 culminating in a comprehensive design report and oral presentation of the final design.

AgEn 5910w. AGRICULTURAL WASTE MANAGEMENT ENGINEERING. (4 cr; prereq upper div IT or grad IT major, 3052, Chem 1052, CE 3400; 3 lect, 3 lab hrs per wk)
Sources and characteristics of agricultural wastes including livestock, food processing, and domestic wastes. Physical, biological, chemical, rheological, and microbiological properties. Effects on the environment. Collection, storage, treatment (aerobic and anaerobic), and utilization/disposal. Land application of livestock and food processing wastes, municipal effluents, and sludges. On-site sewage treatment.

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(For descriptions, see *Graduate School Bulletin*)

AgEn 8000. SUPERVISED TEACHING EXPERIENCE

AgEn 8100. SEMINAR

AgEn 8190, 8191, 8192. ADVANCED PROBLEMS AND RESEARCH

AgEn 8500. HYDROLOGIC MODELING—SMALL WATERSHEDS

AgEn 8700. MOISTURE AND HEAT TRANSFER

Astronomy (Ast)

Ast 1011. DESCRIPTIVE ASTRONOMY. (4 cr, §1021; 4 lect hrs per wk)
The sun, the moon, the planets and their relationships; stars, galaxies, cosmology, and the physical universe.

Ast 1015. DESCRIPTIVE ASTRONOMY LABORATORY. (1 cr, §1025H; prereq high school algebra; high school trigonometry recommended; 1 lab hr per wk)
The human place in the universe. Study of Earth as a planet, other planets, the sun, stars, galaxies. Background and fragility of life on Earth. Scale, origin, and history of the universe and our relationship to it.

Ast 1019. OUR CHANGING PLANET. (4 cr, §EEB 1019, §Geo 1019; 3 lect, 2 active learning session hrs per wk)
Interrelationships among Earth's subsystems—solid earth, oceans, atmosphere, and biosphere—and solar and galactic super-systems. Interactions of the natural cycles, their rates and feedbacks, and human impacts.

Ast 1021H. 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.

Ast 1025H. INTRODUCTION TO ASTRONOMY LABORATORY. (1 cr, §1015; prereq high school algebra, trigonometry, and physics or chemistry; 1 lab hr per wk)
Lab offered in conjunction with 1011 or 1021H. Only opportunity to observe with telescope. Occasional nighttime observing sessions required. A more mathematical and physical discussion than 1015.

Ast 1031. EXPLORING THE UNIVERSE A. (4 cr; 3 lect, 1 active learning session hrs per wk)
The human place in the universe. Study of Earth as a planet, other planets, the sun, stars, galaxies. Background and fragility of life on Earth. Scale, origin, and history of the universe and our relationship to it.

Ast 1032. EXPLORING THE UNIVERSE L. (4 cr; 3 lect, 2 lab hrs per wk)
The human place in the universe. Study of Earth as a planet, other planets, the sun, stars, galaxies. Background and fragility of life on Earth. Scale, origin, and history of the universe and our relationship to it.

Ast 1040. MATHEMATICS AND OUR UNIVERSE. (4 cr; 3 lect hrs, 1 active learning session hr per wk)
Exploration of selected topics in astronomy to illustrate how basic mathematical concepts and reasoning are used to further our understanding of the universe. Emphasis on using an intellectually stimulating discipline to introduce and explore mathematical modes of thinking.

Ast 1201. TOPICS IN MODERN ASTROPHYSICS. (4 cr; prereq 1011 or 1021 or equiv)
Current research problems in astronomy and astrophysics. Nonmathematical.

Ast 3051. ASTROPHYSICS. (4 cr; prereq 1 yr calculus, Phys 1254 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.

Ast 3970. DIRECTED STUDIES. (1-5 cr; prereq #, Δ)
Independent, directed study in observational and theoretical astrophysics areas arranged by student with faculty member.

Ast 5010. ASTRONOMY FROM A PHYSICAL PERSPECTIVE. (3 cr; prereq intro astronomy, 1 yr physics, 1 addl yr any physical science or #)
For secondary science teachers wishing to gain a deeper understanding of the physical basis for astronomical phenomena. Astronomical roles played by gravitation, energy, and radiation.

Ast 5061. COMPUTATIONAL METHODS IN THE PHYSICAL SCIENCES I. (4 cr, §Phys 5061; prereq CLA jr or sr or upper div IT or grad student or #; 2 lect, 6 lab hrs per wk)
Introduction to the solution of problems in the physical sciences with computer programs. Selected numerical methods and general spirit of mapping problems onto computational algorithms. Arranged lab at scientific computer work station.

Ast 5062. COMPUTATIONAL METHODS IN THE PHYSICAL SCIENCES II. (4 cr, §Phys 5062; prereq Phys/Ast 5061, CLA jr or sr or upper div IT or grad student or #; 2 lect, 6 lab hrs per wk)
Introduction to advanced techniques in computer simulation through examples from classical statistical mechanics, classical electrodynamics, and fluid dynamics. Computer experiments using SUN systems and their graphics capabilities.

Ast 5063. COMPUTATIONAL METHODS IN THE PHYSICAL SCIENCES III. (4 cr, §Phys 5063; prereq CLA jr or sr or upper div IT or grad student, Phys/Ast 5062 or #; 2 lect, 6 lab hrs per wk)
Simulation of complex physical systems by advanced computational techniques using the Supercomputer Institute Cray-2 and/or Cyber 205. Major project selected by student in areas such as plasmas, stellar systems and evolution, magnetohydrodynamics, fluid or aerodynamic flow, molecular dynamics, statistical mechanics.

Ast 5161. ASTROPHYSICS OF DIFFUSE MATTER. (4 cr; prereq 3051, Phys 5024 or #)
Survey of physical processes in diffuse matter—gas dynamics, MHD, excitation processes, and equilibria in atoms and molecules. Emission and absorption by gas and dust. Dynamical processes in interstellar space, HII regions, and molecular clouds.

Ast 5162. STARS AND STELLAR EVOLUTION. (4 cr; prereq 3051, Phys 3513 or 3501 or #)
Survey of stars and stellar evolution. Stellar atmospheres, structure and evolution of single stars. White dwarfs, neutron stars, black holes, novae and supernovae. Formation of stars.

Ast 5163. GALACTIC ASTRONOMY AND THE INTERSTELLAR MEDIUM. (4 cr; prereq 3051 or #)
Survey of structure, kinematics, and evolution of Milky Way Galaxy and its constituents, stars, star clusters, and interstellar medium. Emphasis on observed properties of the Galaxy.

Ast 5164. EXTRAGALACTIC ASTRONOMY. (4 cr; prereq 5163 or #)
Structure and evolution of external galaxies. Classification, stellar and gaseous contents, kinematics and dynamics, extragalactic distance scale, clusters, galactic nuclei and associated activity.

Ast 5165. COSMOLOGY. (4 cr; prereq Phys 3513 or #)
Large-scale structure and history of the universe. Introduction to Newtonian and relativistic world models, Big Bang model, microwave background, physics of early universe; cosmological tests, measurement of Hubble constant and deceleration parameter, galaxy formation.

Ast 5201s. METHODS OF EXPERIMENTAL ASTROPHYSICS. (4 cr; prereq 3051, Phys 3513; 2 lect, 6 lab hrs per wk)
Contemporary astronomy techniques and instrumentation. Students make astronomical observations that include data acquisition and instrument control using facilities at O'Brien Observatory as well as data reduction and image processing using department computing facilities.

Ast 5299H. SENIOR HONORS ASTROPHYSICS RESEARCH SEMINAR. (1 cr; prereq IT or CLA upper div honors student, #; 1 seminar hr per wk; S-N only)
An honors opportunity for upper division astronomy and astrophysics majors in the honors program, based on the departmental research seminar.

Ast 5321. RADIATION PROCESSES IN ASTROPHYSICS. (4 cr; prereq Phys 5024, 5102 or #)
Physics of radiation by atoms and molecules. Radiation by energetic charged particles and plasma emission processes. Emission and absorption of radiation by solid particles. Transfer of continuum radiation and formation of spectral lines. Application to various astrophysical environments.

Ast 5362. STELLAR ASTROPHYSICS. (4 cr; prereq 5321 or #)
Theory of stellar structure and evolution. Basic physics and equations of stellar structure. Application to stellar interiors and atmospheres. Nucleosynthesis.

Ast 5421. HIGH ENERGY ASTROPHYSICS. (4 cr; prereq 3051, Phys 5024, 5101 or #)
Study of energetic phenomena in the Universe. Supernovae, pulsars, radio, and X-ray stars. Radio galaxies and quasars. Acceleration of high energy particles. Observational basis and current theoretical understanding.

Ast 5970. DIRECTED STUDIES. (1-5 cr; prereq #, Δ)
Independent, directed study in observational and theoretical astrophysics in areas arranged by the student with a faculty member. Intended for senior astrophysics majors.

Ast 5990. DIRECTED RESEARCH. (3 cr minimum; prereq #, Δ)
Independent research in observational or theoretical astrophysics under the direction of a faculty member. Intended for senior astrophysics majors.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

Ast 8200.* SEMINAR: ASTROPHYSICS AND SPACE PHYSICS

Ast 8481, 8482, 8483.* TOPICS IN ASTROPHYSICS

Ast 8990. RESEARCH IN ASTRONOMY AND ASTROPHYSICS

Phys 8081-8082.* GENERAL RELATIVITY

Phys 8161.* ATOMIC AND MOLECULAR PHYSICS

Phys 8163-8164.* PLASMA PHYSICS

Phys 8400.* SEMINAR: COSMIC RAY AND SPACE PHYSICS

Phys 8411-8412.* COSMIC RAY AND SPACE PHYSICS

Phys 8421-8422.* SOLAR AND MAGNETOSPHERIC PHYSICS

Chemical Engineering (ChEn)

ChEn 3001. PROGRAMMING FOR COMPUTATIONAL METHODS. (2 cr; prereq ChEn or MatS major; 1 lect, 2 lab hrs per wk)
Programming and computing topics relevant for implementing numerical methods for mathematical equations encountered in chemical engineering and materials science. Computer usage (developing, debugging, and running code), programming in Microsoft QuickBASIC, generating graphs with a BASIC plotting library.

ChEn 3090, 3091, 3092. INDUSTRIAL EMPLOYMENT. (1-2 cr depending on duration of employment and character of professional training received) Employment with chemical industry, opportunity for professional training in chemical engineering. Report covering work period required.

ChEn 5001. COMPUTATIONAL METHODS IN CHEMICAL ENGINEERING AND MATERIALS SCIENCE. (4 cr, §MatS 5001; prereq ChEn or MatS major, 3001 or FORTRAN course; 3 lect, 2 computer lab hrs per wk) Analysis of representative chemical engineering problems by computer and mathematical methods.

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

ChEn 5102. PRINCIPLES OF CHEMICAL ENGINEERING II. (4 cr; prereq upper div ChEn major, 5001, 5101; 3 lect, 2 rec hrs per wk) Staff
Fluid dynamics and its applications to chemical engineering unit operations.

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

ChEn 5104. UNIT OPERATIONS AND SEPARATION PROCESSES. (4 cr; prereq upper div ChEn or MatS major, 5103; 3 lect, 2 rec hrs per wk) Staff
Absorption, extraction, distillation, stagewise and continuous separations.

ChEn 5201. THERMODYNAMICS AND MATERIAL STATES. (4 cr; prereq upper div ChEn major, 5001, 5101, Chem 5534 or #; 3 lect, 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.

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

ChEn 5301. CHEMICAL REACTOR ANALYSIS. (4 cr; prereq upper div ChEn major, 5202; 3 lect, 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.

ChEn 5302. APPLIED REACTOR ANALYSIS. (4 cr; prereq 5301 or equiv)
Practical chemical reaction systems and the reactors for them. Catalysis and its role in the chemical industry. Analysis of functioning chemical reaction systems involving ammonia synthesis, polymerization reactors, combustion, and sulfur dioxide removal.

ChEn 5401. CHEMICAL ENGINEERING LABORATORY. (4 cr per qtr; prereq upper div ChEn major, 5102, ¶5103; 4 lab, 1 lect, 1 lab conf hrs per wk) Applications of unit operations; principles of fluid flow, heat and mass transfer; experiments with reports.

ChEn 5402. CHEMICAL ENGINEERING LABORATORY. (4 cr per qtr; prereq upper div ChEn major, 5401; 4 lab, 1 lect, 1 lab conf hrs per wk) Applications of unit operations; principles of fluid flow, heat and mass transfer; experiments with reports.

ChEn 5455. ELECTROCHEMICAL ENGINEERING. (4 cr, §MatS 5455; prereq upper div IT or grad, 5201 or MatS 5101 or #; 4 lect hrs per wk)
Electrokinetics, thermodynamics of cells, practical and advance cells (batteries), fuel cells, electrosynthesis, modern sensors.

ChEn 5501. PROCESS EVALUATION AND DESIGN. (4 cr; prereq upper div ChEn major, 5104, 5301, 5402; 3 lect, 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.

ChEn 5502. PROCESS EVALUATION AND DESIGN. (4 cr; prereq upper div ChEn or MatS, major, 5501, 5601; 3 lect, 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).

ChEn 5601. PROCESS CONTROL. (4 cr; prereq upper div ChEn major, 5104, 5301 or #; 3 lect, 2 rec hrs per wk)
Elementary theory of control and its application to chemical processes. Synthesis of feedback control loops for linear systems.

ChEn 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.

ChEn 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.

ChEn 5640. POLYMERIZATION REACTOR ENGINEERING. (3 cr; prereq ChEn reactor design course or #; 3 lect hrs per wk)
Analysis and design of polymerization reactors. Mathematical modeling techniques, chain-growth and step-growth polymerization, copolymerization, composition and sequence distributions, and molecular weight distributions with emphasis on nonlinear polymerization and network formation.

ChEn 5751. BIOCHEMICAL ENGINEERING I. (3 cr; prereq ChEn sr or grad or #; 3 lect hrs per wk)
Applications of material and energy balances and concepts from thermodynamics, kinetics, and transport phenomena to cellular and enzyme systems.

ChEn 5752. BIOCHEMICAL ENGINEERING II. (3 cr; prereq Biol 5001, ChEn sr or grad or #; 3 lect hrs per wk)
Engineering analysis and design of cellular and enzyme systems for production of chemical commodities.

ChEn 5753. BIOCHEMICAL ENGINEERING III. (3 cr; prereq Biol 5001, ChEn sr or grad or #; 3 lect hrs per wk)
Description and analysis of methods of separation of biochemical products of cellular and enzyme activity; applications to process synthesis.

ChEn 5754. FOOD PROCESSING TECHNOLOGY. (4 cr; prereq 5103 or #; 3 lect hrs per wk)
Heat transfer in food processing; protein processing; financial evaluation of projects; case studies; discussions of marketing, government regulation, nutrition.

ChEn 5756. BIOCHEMICAL ENGINEERING LABORATORY. (2 cr; prereq 5751 or 5752; 4 lab hrs per wk)
Lab projects involving studies of microbial growth; biochemical product formation, isolation, and purification; medium sterilization.

ChEn 5761. SCIENCE AND TECHNOLOGY OF POROUS MEDIA. (3 cr; 3 lect hrs per wk)
Fundamentals of structure of porous media and of flow, transport, and deformation in them. Relations of macroscopic properties and behavior to underlying microscopic structures and mechanisms. Examples from nature and technology, with special reference to in situ processing and enhanced recovery.

ChEn 5771. COLLOIDS AND DISPERSIONS. (3 cr; prereq physical chemistry; 3 lect hrs per wk)
Preparation, stability, and coagulation kinetics of colloidal solutions. Topics include DLVO theory, electrokinetic phenomena, and properties of micelles and other microstructures.

ChEn 5774. INTERFACIAL PHENOMENA OF LIQUIDS. (3 cr; prereq physical chemistry, 5102 or equiv; 3 lect hrs per wk)
Surface tension, surface geometry and capillarity, thin-films and disjoining pressure, contact angle; capillarity-driven and surface tension gradient-driven flows; wetting, spreading, dewetting and retraction; surfactant effects; fluid displacement, detergency, flotation, dynamic wetting, entrainment, adhesion. Examples from science and technology.

ChEn 5780. PRINCIPLES OF MASS TRANSFER IN ENGINEERING AND BIOLOGICAL ENGINEERING. (3 cr; prereq upper div Eng or science major)
Principles of mass transfer in gases, liquids, biological and macromolecular solutions, gels, solids, membranes, capillaries, and porous solids. Interaction between mass transfer and chemical reaction. Applications in biological, environmental, mineral, chemical engineering systems.

ChEn 5810. PROCESSING OF ELECTRONIC MATERIALS. (3 cr; prereq MatS 5011 or #; 3 lect hrs per wk)
Materials science and chemical engineering aspects of processing of materials for microelectronic devices (e.g., semiconductor memories, microprocessors) and optical devices (e.g., semiconductor lasers, optical wave guides).

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

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

ChEn 8004. PHYSICAL RATE PROCESSES

ChEn 8005. PHYSICAL RATE PROCESSES

ChEn 8101. INTERMEDIATE FLUID MECHANICS

ChEn 8102. PROBLEMS IN FLUID MECHANICS

ChEn 8103. TENSORS AND THEORY WITH APPLICATIONS

ChEn 8104. INTERFACES AND INTERFACIAL PHENOMENA

ChEn 8105. PRINCIPLES AND APPLICATIONS OF RHEOLOGY

ChEn 8201-8202-8203. ADVANCED MATHEMATICS FOR CHEMICAL ENGINEERS

ChEn 8301-8302. PHYSICAL AND CHEMICAL THERMODYNAMICS

ChEn 8401-8402. CHEMICAL REACTION KINETICS—KINETICS OF HOMOGENEOUS REACTIONS

ChEn 8403. CHEMICAL REACTION KINETICS—ADVANCED TOPICS

ChEn 8500. INTERMEDIATE CHEMICAL REACTOR ANALYSIS

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

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

ChEn 8640. POLYMERIZATION REACTOR ENGINEERING

ChEn 8701. ANALYSIS OF CHEMICAL ENGINEERING PROBLEMS

ChEn 8702. ADVANCED TOPICS IN CHEMICAL ENGINEERING

ChEn 8703. PROCESS CONTROL

ChEn 8750. ADVANCED CHEMICAL PROCESS DESIGN

ChEn 8801-8802-8803. SEMINAR

ChEn 8810. PROCESSING OF ELECTRONIC MATERIALS

ChEn 8850. GENERAL SURVEY OF CHEMICAL ENGINEERING

ChEn 8901, 8902, 8903. RESEARCH IN CHEMICAL ENGINEERING

Chemistry (Chem)

High School Chemistry—All course offerings are intended for students who have taken high school chemistry. Completion of at least one course in high school chemistry is a *prerequisite* for Chem 1001 or 1051. All students taking Chem 1051 are required to take the chemistry placement examination. For more information, contact General Chemistry, 115 Smith Hall, 207 Pleasant Street S.E., Minneapolis, MN 55455 (612/624-0026).

Deposit Card—Each student must present a deposit card for admission to lab sections. See the *Class Schedule* for details.

Chem 1001. GENERAL PRINCIPLES OF CHEMISTRY. (4 cr, §1003, §1008; for students not passing placement examination; prereq high school chemistry or equiv, 2 yrs high school mathematics; high school physics and 4 yrs high school mathematics recommended; 3 lect, 1 lab discussion, one 3-hr lab per wk)
Introduction to chemistry, matter and energy, atoms, molecules, chemical bonding, mole and chemical calculations, gases, liquids, solids, chemical reactions, acids, base, equilibrium.

Chem 1002. ELEMENTARY ORGANIC CHEMISTRY. (4 cr, §3301, §3302; primarily for nursing and forestry students; all IT students excluded without special permission; terminal course; prereq 1001 or passing placement examination; 3 lect, 1 lab discussion, one 3-hr lab per wk)
Brief introduction to organic chemistry with emphasis on biological systems.

Chem 1003. PHYSICAL WORLD, CHEMISTRY. (See *College of Liberal Arts Bulletin*)

Chem 1008. PHYSICAL WORLD, CHEMISTRY. (4 cr, §any other college chemistry course; prereq 1 yr high school algebra; high school chemistry recommended; terminal course; cannot be used as prereq for any other advanced chemistry course; 4 lect hrs per wk)
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.

Chem 1051-1052. CHEMICAL PRINCIPLES I-II. (4 cr per qtr; primarily for science or engineering majors; prereq 1001 or passing placement examination; 3 lect, 1 lab discussion, one 3-hr lab per wk)
Atomic theory; periodic properties of elements; chemical thermodynamics; development of structural concepts; geometry of molecules; bonding theory; behavior of gaseous and liquid states; solid state and materials; chemistry; dynamics; equilibrium; behavior of solutions; acids and bases; descriptive chemistry of elements and compounds; applications to environmental problems.

Chem 1051H-1052H. HONORS CHEMICAL PRINCIPLES I-II. (4 cr per qtr; prereq selection for IT honors curriculum or consent of IT Honors Office, 1001 or passing placement examination; 3 lect, 1 lab discussion, one 3-hr lab per wk)
For description see 1051-1052.

Chem 3100. QUANTITATIVE ANALYSIS LECTURE. (3 cr; for non-chemistry majors; prereq 1052; 3 lect hrs per wk)
Introduction to the theory of quantitative chemical analysis.

Chem 3101. QUANTITATIVE ANALYSIS LABORATORY. (2 cr; prereq 3100 or ¶3100; two 4-hr labs per wk)
Introductory lab in quantitative chemical analysis.

Chem 3301. ORGANIC CHEMISTRY I. (4 cr; prereq 1052 or equiv; 4 lect hrs per wk)
Important classes of organic compounds, their constitutions, configurations, and conformations; relationship between molecular structure and chemical reactivity.

Chem 3302. ORGANIC CHEMISTRY II. (4 cr; prereq 3301, 3305 or ¶3305; 4 lect hrs per wk)
Reactions of organic compounds, nucleophilic substitution and addition; electrophilic substitution and addition; elimination reactions; molecular arrangements; oxidation and reduction.

Chem 3303. ORGANIC CHEMISTRY III. (4 cr; prereq 3302, 3306 or ¶3306; 4 lect hrs per wk)
Chemical reactivities and methods for the synthesis and structural characterization of biologically important classes of organic compounds such as lipids, carbohydrates, amino acids, peptides, proteins, nucleotides, nucleosides, and nucleic acids.

Chem 3305. ORGANIC CHEMISTRY LABORATORY I. (2 cr; prereq 3301 or ¶3301; 1 lab conf, one 4-hr lab per wk)
Lab techniques used in the preparation, purification, and characterization of typical organic substances.

Chem 3306. ORGANIC CHEMISTRY LABORATORY II. (2 cr; prereq 3302 or ¶3302, 3305; 1 lab conf, one 4 hr-lab per wk)
Continuation of 3305.

Chem 3335H-3336H. HONORS ORGANIC CHEMISTRY LABORATORY. (5 cr for sequence, §3305, §3306, §3336; prereq 3301 or ¶3301, #, Chem, ChEn, BioC majors only; A-F only)
Honors organic chemistry lab to take the place of 3305, 3306, and 3336.

Chem 3336. ORGANIC CHEMISTRY III LABORATORY. (3 cr; prereq 3302, 3306; A-F only; 1 lect, two 4-hr labs per wk)
Emphasis on the use of instrumentation routinely used in support of experimental work in organic chemistry.

Chem 3701 (formerly 5731). INTRODUCTION TO INORGANIC CHEMISTRY. (4 cr; prereq 3302 or ¶3302; 4 lect hrs per wk)
Introduction to inorganic chemistry. Periodic trends. Structure and bonding concepts in compounds in which *s* and *p* electrons are important. Descriptive chemistry of solids and transition metal compounds.

Chem 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.

Chem 3991, 3992, 3993. SPECIAL TOPICS IN CHEMISTRY. (1 cr; prereq 1 qtr 1xxx-level chemistry or #; S-N only; 1 lect per wk)
Topics in chemistry—opportunities and current research.

Chem 5001-5002. CHEMISTRY CONCEPTS FOR JUNIOR HIGH SCHOOL TEACHERS. (4 cr; prereq college-level general chem, secondary school tchg exper or #; restricted to secondary school teachers or College of Education and Human Development students)
Chemistry fundamentals to augment and expand the resources of junior high school science teachers for the teaching of chemistry concepts. Emphasis on demonstration of chemical ideas by experiments and selecting chemistry topics appropriate for junior high school students.

Chem 5122. ADVANCED ANALYTICAL CHEMISTRY. (4 cr; prereq 3302, 5501 or 5534; 3 lect hrs per wk)
Equilibria in aqueous and nonaqueous systems.

Chem 5126. MODERN ANALYTICAL CHEMISTRY. (4 cr; prereq 3302, 3306, ChEn major only; two 1½-hr lect, one 4-hr lab per wk)
Strategies and techniques for solving modern analytical problems. Use of modern instruments in analysis.

Chem 5127. ANALOG INSTRUMENTATION. (5 cr; prereq Chem major or grad, Phys 1253, Math 3251 or equiv or #; three 1½-hr lect, one 3-hr lab per wk)
Basic principles of electronic circuitry; servo systems, operational amplifiers, feedback control, oscillators, and converters for signal processing and control of chemical measurement systems.

Chem 5128. THE SMALL COMPUTER IN THE CHEMICAL LABORATORY. (5 cr; prereq 5127 or #; two 1¼-hr lect, two 4-hr labs per wk)
Applications of the lab computer to the control of chemical instrumentation and acquisition of data. Hardware (interfacing) and software (assembly language programming) aspects of automating the chemical experiment.

Chem 5130. ANALYTICAL CHEMISTRY. (3 cr; prereq 3302, 3306; 3 lect hrs per wk)
Primarily for chemistry majors. Methods and concepts of measurement by chemical and instrumental analysis, including titrimetry, quantitative spectrophotometric analysis, chromatographic separations, and equilibrium and rate methods emphasizing applications to organic and biochemical systems.

Chem 5131. ANALYTICAL CHEMISTRY LABORATORY. (2 cr; prereq 5130 or ¶5130; two lab lect, two 3-hr labs per wk)
Lab for 5130. High precision methods, acidimetry and complexometry, single and multi-component analysis by spectrophotometry, analysis of mixtures by ion exchange and gas chromatography, enzymatic and rate methods.

Chem 5133. CHEMICAL INSTRUMENTATION AND ANALYSIS LECTURE. (3 cr, §5126; prereq 5130, 5131, 5501 or 5534; 3 lect hrs per wk)
Methodology and practices of solving analytical problems. Application of modern instrumental techniques.

Chem 5139. CHROMATOGRAPHY AND SEPARATION SCIENCE. (4 cr; prereq Chem major or grad, 5133, 5140 or equiv or #; three 1½-hr lect per wk)
Fundamental and practical aspects of gas liquid chromatography, modern liquid chromatography, and other techniques used for analysis and separations.

Chem 5140. CHEMICAL INSTRUMENTATION AND ANALYSIS LABORATORY. (3 cr, §5126; prereq 5133, Chem major; 1 rec, two 4-hr labs per wk)
Instrumental techniques including spectroscopic methods of analysis, electrochemical methods of analysis, and analysis based on separation. Emphasis on the use of computers in data collection and reduction.

Chem 5302. INTERPRETATION OF ORGANIC SPECTRA. (4 cr, §8302; prereq 3303 or equiv; 4 lect hrs per wk)
Practical application of nuclear magnetic resonance, mass, ultraviolet and infrared spectral analysis to solution of organic structural problems.

Chem 5311. ORGANIC SYNTHESIS I. (4 cr, §8311; prereq 3303 or equiv or #; 3 lect hrs per wk)
Fundamental concepts, reactions, reagents, structural and stereochemical issues, and mechanistic skills necessary for understanding organic chemistry.

Chem 5312. ORGANIC SYNTHESIS II. (4 cr, §8312; prereq 5311 or #; 3 lect hrs per wk)
Topics may include complex carbon skeleton synthesis, asymmetric synthesis, modern studies in organic chemistry.

Chem 5331. ADVANCED ORGANIC CHEMISTRY I. (4 cr, §8331; prereq 3303, #; 3 lect hrs per wk)
Topics may include heterocyclic chemistry, natural products chemistry, organic electrochemistry, synthetic applications of organometallic chemistry, solid-state chemistry, polymer chemistry, stereochemistry.

Chem 5332. ADVANCED ORGANIC CHEMISTRY II. (4 cr, §8332; prereq 3303, #; 3 lect hrs per wk)
Topics may include heterocyclic chemistry, natural products chemistry, organic electrochemistry, synthetic applications of organometallic chemistry, solid-state chemistry, polymer chemistry, stereochemistry.

Chem 5501 (formerly 5520). INTRODUCTION TO THERMODYNAMICS AND KINETICS. (4 cr, §5534; prereq 1052, Math 3251 or equiv, Phys 1106 or Phys 1253 or ¶1253; 4 lect hrs per wk)
Basic thermodynamics with applications to chemical and biological systems. Development of concepts (enthalpy, entropy, Gibbs free energy, chemical potential) needed to understand the equilibrium properties of bulk matter and its physical and chemical changes. Brief introduction to chemical kinetics.

Chem 5502 (formerly 5521). INTRODUCTION TO QUANTUM THEORY AND SPECTROSCOPY. (4 cr; prereq 1052, Math 3251, Phys 1106 or 1253; 4 lect hrs per wk)
Introduction to quantum theory and the electronic structures of atoms and molecules. Spectroscopic techniques widely used by chemists and biochemists, including vibrational (IR, Raman), electronic (UV/vis, photoelectron) and spin (NMR, ESR) spectroscopies.

Chem 5525. PHYSICAL BIOCHEMISTRY: SOLUTION STRUCTURE AND INTERACTIONS OF BIOLOGICAL MACROMOLECULES. (4 cr, §BioC/MdBc 5525; prereq 2 qtrs physical chemistry, BioC 5331 or equiv; two 1-hr lect per wk)
Physical chemistry of equilibrium, transport, and scattering phenomena in solution, with application to proteins and nucleic acids. Intermolecular forces, macromolecular dynamics, conformational transitions, binding thermodynamics, methods for determining biopolymer size and shape, including sedimentation, diffusion, viscosity, electrophoresis, and scattering.

Chem 5526. PHYSICAL BIOCHEMISTRY: SPECTROSCOPIC METHODS I. (4 cr, §BioC/MdBc 5526; prereq 2 qtrs physical chemistry; two 1½-hr lect per wk)
Fundamental spectroscopic principles with emphasis on development of magnetic resonance theory used in the study of biological macromolecules.

Chem 5527. PHYSICAL BIOCHEMISTRY: SPECTROSCOPIC METHODS II. (4 cr, §BioC/MdBc 5527; prereq 2 qtrs physical chemistry; two 1½-hr lect per wk)
Application of optical and magnetic resonance techniques to the study of structure and dynamics in proteins, lipids, nucleic acids, and synthetic analogs.

Chem 5528. PHYSICAL BIOCHEMISTRY: ENZYME KINETICS. (4 cr, §BioC/MdBc 5528; prereq 2 qtrs physical chemistry, BioC 5331 or BioC/MdBc 8001 or equiv desirable; two 1½-hr lect per wk)
Theory and application of steady-state and transient kinetics to the study of enzymes, enzyme systems, and cellular regulation.

Chem 5529. PROTEIN STRUCTURE AND FOLDING. (4 cr, §BioC/MdBc 5529; prereq BioC 5331 or equiv, 1 qtr physical chemistry or #; two 1½-hr lect per wk)
Advanced course on protein structure, stability, folding, and molecular modeling. Results from X-ray crystallography, solution thermodynamics, NMR, computer graphics, and protein engineering.

Chem 5533. QUANTUM CHEMISTRY. (4 cr; prereq 1052, Math 3252 or ¶Math 3252 or Math 3261 or ¶Math 3261, Phys 1253 or ¶Phys 1253; 4 lect hrs per wk)
Principles of quantum mechanics with applications to atomic and molecular structure and to spectroscopy.

Chem 5534. CHEMICAL THERMODYNAMICS. (4 cr, §Chem 5501; prereq upper div IT or CLA Chem major or Δ, 1052, Math 3251, Phys 1253 or ¶Phys 1253 or Phys 1106 with #; 4 lect hrs per wk)
Principles of thermodynamics with applications to chemical systems.

Chem 5535. STATISTICAL MECHANICS AND REACTION KINETICS. (4 cr; prereq 5501 or 5534; 4 lect hrs per wk)
Statistical thermodynamics and the kinetic theory of gases with applications to reaction rate theory. Phenomenological kinetics and experimental methods.

Chem 5538. PHYSICAL CHEMISTRY LABORATORY. (1 cr; prereq 5501 or 5535 or ¶5535; not open to Chem majors; one 3-hr lab per wk)
Experiments in thermodynamics and reaction kinetics.

Chem 5540. PHYSICAL CHEMISTRY LABORATORY. (3 cr; prereq 5502 or 5533, Chem majors only; 1 rec, one 4-hr lab per wk)
Lab experiments illustrating principles and methods of thermodynamics, reaction kinetics, and quantum mechanics.

Chem 5610. PRINCIPLES OF POLYMER SCIENCE. (3 cr, §8610, §MatS 5610; prereq upper div, 3301 or #; 3 lect 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.

Chem 5702 (formerly 5732). INTERMEDIATE INORGANIC CHEMISTRY. (4 cr; prereq 3701, 5501 or ¶5501 or 5534 or ¶5534; 4 lect hrs per wk)
Emphasis on transition metal chemistry. Advanced topics in main group and materials chemistry.

Chem 5740. INORGANIC CHEMISTRY LABORATORY. (3 cr; prereq 5702 or ¶5702, Chem majors only; 1 lect, two 4-hr labs per wk)
Lab experiments in inorganic and organometallic chemistry illustrating synthetic and spectroscopic techniques.

Chem 5803. THE CHEMISTRY OF INDUSTRY. (4 cr; prereq Chem sr or grad or #; 3 lect hr per wk)
Industrial and polymer chemistry technology. Relationship of basic properties to industrial utility. Emphasis on economics, social problems, and the industrial environment.

Chem 5970. DIRECTED STUDY. (Cr ar; prereq any 5xxx Chem course, #)
On- or off-campus learning experiences individually arranged between student and chemistry faculty member, in areas not covered by regular courses.

Chem 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 descriptions, see *Graduate School Bulletin*)

Chem 8001. APPLIED CHEMICAL THERMODYNAMICS

Chem 8002. MECHANISMS OF CHEMICAL REACTIONS

Chem 8003. COMPUTATIONAL CHEMISTRY

Chem 8104. SPECTROSCOPIC METHODS OF ANALYSIS

Chem 8133. MODERN ELECTROANALYTICAL TECHNIQUES, PRINCIPLES, AND PRACTICES

Chem 8134. BIOANALYTICAL CHEMISTRY

Chem 8135. MASS SPECTROMETRY

Chem 8136. SURFACE AND THIN FILM ANALYSIS

Chem 8190. SEMINAR: MODERN PROBLEMS IN CHEMISTRY INSTRUMENTATION AND ANALYSIS

Chem 8191. SEMINAR PRESENTATION: MODERN PROBLEMS IN CHEMICAL INSTRUMENTATION AND ANALYSIS

Chem 8290 SEMINAR: MATERIALS CHEMISTRY

Chem 8291. SEMINAR PRESENTATION: MATERIALS CHEMISTRY

Chem 8302. INTERPRETATION OF ORGANIC SPECTRA

Chem 8311. ORGANIC SYNTHESIS I

Chem 8312. ORGANIC SYNTHESIS II

Chem 8321. PHYSICAL ORGANIC CHEMISTRY I

Chem 8322. PHYSICAL ORGANIC CHEMISTRY II

Chem 8331. ADVANCED ORGANIC CHEMISTRY I

Chem 8332. ADVANCED ORGANIC CHEMISTRY II

Chem 8390. SEMINAR: ORGANIC CHEMISTRY

Chem 8391. SEMINAR PRESENTATION: ORGANIC CHEMISTRY

Chem 8401. BIOORGANIC CHEMISTRY I

Chem 8402. BIOORGANIC CHEMISTRY II

Chem 8403. BIOORGANIC CHEMISTRY III

Chem 8404. BIOORGANIC CHEMISTRY IV

Chem 8512. CHEMICAL THERMODYNAMICS

Chem 8521. METHODS OF THEORETICAL CHEMISTRY

Chem 8531-8532-8533. INTRODUCTORY QUANTUM MECHANICS AND SPECTROSCOPY

Chem 8535. MOLECULAR QUANTUM MECHANICS

Chem 8545. REACTION DYNAMICS

Chem 8547. ELEMENTS OF STATISTICAL MECHANICS

Chem 8548. ADVANCED STATISTICAL MECHANICS

Chem 8560. SEMINAR: BIOLOGICAL SYSTEMS

Chem 8561. SEMINAR PRESENTATION: BIOLOGICAL SYSTEMS

Chem 8590. SEMINAR: PHYSICAL CHEMISTRY

Chem 8591. SEMINAR PRESENTATION: PHYSICAL CHEMISTRY

Chem 8611. INTRODUCTION TO POLYMER PROPERTIES

Chem 8612. ADVANCED TOPICS IN POLYMER SCIENCE

Chem 8751. PHYSICAL INORGANIC CHEMISTRY I

Chem 8752. PHYSICAL INORGANIC CHEMISTRY II

Chem 8756. X-RAY CRYSTALLOGRAPHY

Chem 8761. ORGANOMETALLIC CHEMISTRY

Chem 8762. CHEMISTRY OF THE ELEMENTS

Chem 8765. BIOINORGANIC CHEMISTRY

Chem 8766. SOLID STATE CHEMISTRY

Chem 8790. SEMINAR: MODERN PROBLEMS IN INORGANIC CHEMISTRY

Chem 8791. SEMINAR PRESENTATION: MODERN PROBLEMS IN INORGANIC CHEMISTRY

Chem 8881, 8882, 8883. M.S. PLAN B PROJECT I-II-III

Chem 8990. RESEARCH IN CHEMISTRY

Chem 8991, 8992, 8993. SPECIAL TOPICS IN CHEMISTRY

Chem 8994, 8995, 8996, 8997, 8998. SPECIAL TOPICS IN CHEMISTRY

Civil Engineering (CE)

General Courses

CE 1001. CIVIL ENGINEERING ORIENTATION. (1 cr; S-N only)
Fundamentals of civil engineering practice presented by professional engineers and members of the faculty.

CE 3020. COMPUTER APPLICATIONS IN CIVIL ENGINEERING I. (4 cr; prereq CE or GeoE students, Math 1261)
Use of PASCAL, graphics, and numerical techniques such as Bisection, Newton-Raphson, Gauss Elimination, Simpson's Rule, Gauss Quadrature, Predictor-Corrector, and Runge-Kutta for engineering problem solving. Problems drawn from different branches of civil and mineral engineering.

CE 3050. ENGINEERING INTERN WORK ASSIGNMENT. (4 cr; prereq IT student, regis in intern program; S-N only)
Requires submission of two formal written reports, one covering the work completed during the six-month professional assignment and the second involving an in-depth presentation of a related engineering problem.

CE 3051. ENGINEERING INTERN WORK ASSIGNMENT. (4 cr; prereq IT student, regis in intern program; S-N only)
For description, see 3050.

CE 3700. HOW TO MODEL IT. (4 cr, §GeoE 3700; prereq IT student; 4 lect hrs per wk)
Problem formulation, design and construction of models, drawing conclusions from modeling results. Students learn how to use computer-based modeling tools working in small groups on a number of problems from various engineering contexts.

CE 5002. ENGINEERING ECONOMICS. (2 cr; prereq IT jr or above, adult spec or grad; 2 lect hrs per wk)
Time value of money; compound amount factors; present worth of uniform and single payments; cost-benefit analysis; net present worth analysis; internal rate of return.

CE 5004. UNDERGROUND CONSTRUCTION ENGINEERING. (4 cr; prereq upper div IT)
Application of structural and geotechnical techniques to earth-sheltered buildings; construction techniques and problems. Topics include retaining systems, structural loads, drainage systems, waterproofing, site investigation, contracting practices, instrumentation, and heat transfer calculations. Housing, large scale buildings, and mines space.

CE 5010. SENIOR DESIGN PROJECT. (5 cr; prereq CE sr; 4 lect hrs per wk)
Team participation in formulation and solution of open-ended civil engineering problems from conceptual stage through preliminary planning, public hearings, design, and environmental impact statements to preparation of final plans and specifications, and award of contracts.

CE 5021. COMPUTER APPLICATIONS IN CIVIL ENGINEERING II. (4 cr; prereq CE or GeoE upper div, 3020, Math 3251, Math 3252)
Introduction to three methods (finite differences, finite elements, boundary elements) for solution of problems in hydrology, structural engineering, geomechanics, transportation, and environmental engineering that reduce to partial differential equations. Methods illustrated in context of practical problems.

CE 5055. ENGINEERING GEOSTATISTICS. (4 cr, §GeoE 5437; prereq Stat 3091, CE or GeoE or Geo sr or grad or #)
Problem solving and decision making in civil and geological engineering using applied statistics. Emphasis on spatially correlated data, e.g., geologic site characterization, spatial sampling in environmental engineering, optimal sample design for groundwater contamination assessment.

CE 5097, 5098, 5099. ADVANCED DESIGN, ANALYSIS, RESEARCH, OR TUTORIAL IN CIVIL ENGINEERING. (Cr ar; courses may be taken more than once; prereq approval of faculty adviser)
Special studies in the planning, design, or analysis of complex civil engineering systems. Individual lab research problems, literature studies, and reports supervised by staff members. Studies may be conducted in any discipline within civil engineering and hydraulics including, but not limited to, hydraulics and hydrology, land development, materials, sanitary engineering, soil mechanics, structures, and transportation.

CE 5700. SYSTEMS ANALYSIS FOR CIVIL ENGINEERS. (4 cr, §GeoE 5700; prereq upper div IT or grad)
Systems analysis and decision making; expert systems; operations research techniques, modeling, and simulation. Applications in civil engineering and related areas.

CE 5703. PROJECT MANAGEMENT. (4 cr; prereq sr standing, IT major)
Construction project management, including project planning, budgeting, scheduling, staffing, task and cost control, and communicating with, motivating, and managing team members.

Surveying and Mapping

CE 3100. INTRODUCTION TO SURVEYING AND MAPPING. (4 cr; prereq IT student, Math 1251; 3 lect, 3 lab hrs per wk)
Theory of precision measurements of distance, elevation, angle, and direction. Elements of coordinate systems, datum planes, and maps. Fundamentals of vertical and horizontal curvature.

CE 5102. SITE AND ROUTE ENGINEERING. (4 cr; prereq IT or grad student, 3100; 3 lect, 2 lab hrs per wk)
Site and route design fundamentals and problems based on topographic map data. Geometric design; grades, horizontal and vertical curves; fitting of design to topography; earthwork, area and volumes. Horizontal and vertical control.

CE 5104. PHOTOGRAMMETRY. (4 cr; prereq IT or grad student, Math 1251; 3 lect, 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.

Transportation

CE 3200. INTRODUCTION TO TRANSPORTATION ENGINEERING. (4 cr; prereq IT student, Phys 1251)
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. Estimation of demand for transportation system. Location, design, and operation of transportation facilities.

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

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

CE 5210. INTRODUCTION TO TRANSPORTATION SYSTEMS ANALYSIS. (4 cr; prereq #)
Techniques of analysis and planning for transportation services; demand-supply interactions; evaluating transportation alternatives; travel demand forecasting; integrated model systems; citizen participation in decision making; proposal writing.

CE 5304. DESIGN OF HIGHWAY AND AIRPORT PAVEMENTS. (4 cr; prereq IT or grad student, 3300, 5603)
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)

CE 3300. SOIL MECHANICS. (4 cr; prereq IT student, AEM 3016; 3 lect, 3 lab hrs per wk)
Index properties and soil classification; compaction. Effective stress. Permeability and seepage. One-dimensional compression. Strength and failure criteria.

CE 5300. CRITICAL STATE SOIL MECHANICS. (4 cr; prereq upper div IT or grad student, 3300)
Strength of granular soils. Volume changes under shear (dilatancy, contractancy), liquification. Cyclic loading. Strength of cohesive soils. Normal consolidation. Overconsolidation. Critical state concept.

CE 5301. APPLIED SOIL MECHANICS. (4 cr; prereq upper div IT or grad student, 3300; 4 lect hrs per wk)
Consolidation and settlements. Bearing capacity of shallow foundations. Earth pressure theories; rigid and flexible retaining walls. Stability of slopes.

CE 5305. DESIGN OF UNDERGROUND EXCAVATIONS IN ROCK. (4 cr, §GeoE 5218; prereq IT or grad IT major, GeoE 5302 or #)
Stresses and deformations around underground excavations in rock. Design of linings and support systems. Excavations by boring, drill, and blast. Tunneling under adverse conditions. Materials handling and tunnel ventilation.

Water Resources, Hydraulic Engineering, and Hydrology

CE 3400. FLUID MECHANICS. (4 cr; prereq IT student or ForP major, Math 3261, AEM 1015 or 3016; 3 lect, 3 lab hrs per wk)
Fluid statics and dynamics for liquids and gases. Kinematics of fluid flow, viscous effects, and introduction to incompressible and compressible duct flow. Boundary layers, lift and drag, fluid measurements.

CE 5401. WATER RESOURCES ENGINEERING. (4 cr; prereq IT or grad student, 3400 or #; 3 lect, 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.

CE 5402. COMPUTATIONAL HYDRAULICS. (4 cr; prereq IT or grad student, 5401, CSci 3101 or #; 3 lect, 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.

CE 5403. HYDRAULIC STRUCTURES. (4 cr; prereq IT or grad student, 5401 or #)
Hydraulic design procedures for such structures as culverts, dams, spillways, outlet works; river control works; drop structures, water intakes, bridge crossings, pipeline crossings.

CE 5405. HYDROLOGY AND HYDROLOGIC DESIGN. (4 cr; prereq IT or grad student or #; 3 lect, 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.

CE 5410. OPEN CHANNEL HYDRAULICS. (4 cr; prereq IT or grad student, 3400, 5401 or #; 3 lect, 2 rec 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.

CE 5425. GROUNDWATER MECHANICS. (4 cr; prereq IT or grad student, 3400 or #)
Basic equations. Shallow confined and unconfined flows, two-dimensional flow in the vertical plane, and transient flow. Flow from rivers and lakes toward wells. Determination of streamlines and pathlines in two and three dimensions. Introduction to containment transport. Elementary computer modeling.

CE 5426. COMPUTER MODELING OF GROUNDWATER FLOW. (4 cr; prereq IT or grad student, 5425 or #)
Principles of analytic element method. Mathematical and computer modeling of single- and multi-aquifer systems. Applications to actual field problems. Theory and application of contaminant transport models, including capture zone analysis.

CE 5435. INTERMEDIATE FLUID MECHANICS WITH APPLICATIONS. (4 cr; prereq IT or grad student, 3400)
Basic laws and equations of fluid flow, mass transport, and heat transport, with exact and approximate solutions. Derivation of similarity parameters from basic equations. Two- and three-dimensional potential flow.

Environmental Engineering

CE 5500. ANALYSIS AND DESIGN OF WATER SUPPLY SYSTEMS. (4 cr; prereq IT or grad student, 3400, 5401 or #)
Planning and engineering design considerations in developing water supply systems for urban centers. Supply quality, storage, treatment, distribution, and cost analysis.

CE 5501. ANALYSIS AND DESIGN OF WASTEWATER SYSTEMS. (4 cr; prereq IT or grad student, Chem 1052, 3400 or #)
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.

CE 5504. MASS TRANSPORT WITH ENVIRONMENTAL APPLICATIONS. (4 cr; prereq IT or grad student, 3400 or #)
Principles of reactor design for water and wastewater treatment and pollutant transport in the environment.

CE 5505. WATER QUALITY ENGINEERING. (4 cr; prereq IT or grad student, 5506 or #)
Chemical, physical, and biological properties of natural waters; water quality criteria, standards, and legislation; mathematical modeling to predict fate/effects of oxygen-demanding pollutants, nutrients, and refractory organic contaminants on receiving waters.

CE 5506. ENVIRONMENTAL WATER CHEMISTRY. (4 cr; prereq IT or grad student, Chem 1052 or #; 3 lect, 1 rec hrs per wk)
Composition of natural waters and wastewater; chemical processes affecting distribution of chemical species, including pollutants, in water; methods to evaluate fate of organic pollutants.

CE 5507. ENVIRONMENTAL ENGINEERING LABORATORY. (4 cr; prereq upper div IT or grad student, 5500 or 5501, 5506 or #; 3 lect, 3 lab hrs per wk)
Methods of sampling natural water and wastewater; techniques for the chemical, biological, and physical characterization of samples, including nutrients, indicator organisms, BOD, major and minor ions, natural synthetic organic matter.

CE 5510. SOLID AND HAZARDOUS WASTE MANAGEMENT. (4 cr; prereq IT or grad student, Chem 1052 or #)
Solid and hazardous waste characterization; regulatory legislation; waste minimization; resource recovery; chemical, physical, and biological treatment; thermal processes; disposal practices. Analysis and design of systems for treatment and disposal.

CE 5512. SOLID AND HAZARDOUS WASTE PROCESSING I. (4 cr; prereq upper div IT or grad student, 5510 or #; 4 lect hrs per wk)
Application of physical and chemical principles to unit operations and processes for recovering and recycling solid wastes. Remediation and pollution prevention methodologies on solid and hazardous wastes from manufacturing industries, municipal waste treatment plants, electric power utilities, and the mining industry. Student presentations and reports.

CE 5513. SOLID AND HAZARDOUS WASTE PROCESSING II. (4 cr; prereq upper div IT or grad student, 5512 or #; 4 lect hrs per wk)
Continuation of 5512. Pyro-processing and high-temperature treatment approaches; chemistry of high-temperature systems; thermal incineration principles; encapsulation of radioactive waste, developing technologies in high-temperature treatment of hazardous wastes.

CE 5515. WATER AND WASTEWATER MICROBIOLOGY. (4 cr; prereq Chem 1005, Math 1052)
Analysis of role of microbes in environmental degradation and pollution control. Organism growth and selection in wastewater treatment systems. Pathogens in receiving waters and water supplies. Microbial indicators of water quality.

CE 5540. ANALYSIS OF GROUNDWATER SOIL POLLUTION ABATEMENT TECHNOLOGY. (4 cr; prereq IT or grad, 5401, 5501 or #)
Analysis and modeling of chemicals in groundwater and soils. Transport, dispersion, chemical-biological transformations and accumulations. Modeling of in situ cleanup of groundwater and aquifers; simulation of time-dependent changes in pollutant concentration.

CE 5580. INTRODUCTION TO ENVIRONMENTAL LAW FOR ENGINEERS. (4 cr; prereq upper div IT or grad student or #; 4 lect hrs per wk)
Environmental regulatory law relevant to civil and environmental engineering; specific provisions of federal statutory and regulatory laws such as NEPA, CWA, RCRA, CAA, and CERCLA.

Structural Engineering

CE 3600-3601-3602. STRUCTURAL DESIGN FOR ARCHITECTS. (4 cr per qtr; prereq adult spec or AEM 3092, 3093; 4 lect, 1 rec hrs per wk)
Behavior, analysis, design, and construction of structural systems and members in steel, reinforced concrete, timber, masonry, and plastics.

CE 5600. LINEAR STRUCTURAL SYSTEMS. (4 cr; prereq IT or grad student, AEM 3016)
Analysis of determinate and indeterminate linear structural systems; analysis of trusses and frames through virtual work, moment distribution, energy methods, and slope-deflection equations. Influence lines. Approximate methods of analysis. Design considerations.

CE 5601. MATRIX ANALYSIS OF STRUCTURES. (4 cr; prereq IT or grad student, 5600)
Analysis of linear structural systems by matrix methods based on the structural stiffness approach. Introduction to the finite element method and to computerized analysis of structural systems.

CE 5602. TOPICS IN STRUCTURAL MECHANICS. (4 cr; prereq upper div IT or grad student, 5600, AEM 3036)
Introduction to theory of elasticity; theory of vibration for single-degree-of-freedom structures; energy methods of approximate structural analysis; torsion of beams; numerical calculation of buckling heads of bars and plates.

CE 5603. INTRODUCTION TO CONSTRUCTION MATERIALS. (4 cr; prereq upper div IT, AEM 3016)
Basic concepts of behavior mechanisms of materials such as concretes, metals, and woods.

CE 5610. DESIGN OF METAL STRUCTURES: INTRODUCTION. (4 cr; prereq upper div IT or grad student, 5600, ¶5603)
Loads on civil structures. Load factor and working stress philosophies of design. Design of tension, compression, and flexural members and their connections. Codes, properties of structural metals.

CE 5611. DESIGN OF REINFORCED CONCRETE STRUCTURES. (4 cr; prereq upper div IT or grad student, 5600, ¶5603)
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, deflections, cracking, long-term effects. Introduction to design of columns, continuity; simple footings.

CE 5612. DESIGN OF METAL STRUCTURES: INTERMEDIATE. (4 cr; prereq IT or grad student, 5610)
Design of complete metal structures; plate girder bridges, industrial buildings, multistory structural frames.

CE 5613. INTERMEDIATE REINFORCED CONCRETE DESIGN. (4 cr; prereq IT or grad student, 5611; 4 lect hrs per wk)
In-depth treatment of 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.

CE 5615. PRESTRESSED CONCRETE. (4 cr; prereq IT or grad student; 5611, 5612, 5613 recommended; 4 lect hrs per wk)
Types and properties of high-strength concretes and steels for prestressed concretes. Design of pretensioned and post-tensioned members. Post-tensioning systems. Precast, prestressed building systems, floors, roofs, bridges. Continuity in precast, prestressed systems. Design of connections.

CE 5617. DESIGN OF MASONRY STRUCTURES. (4 cr; prereq IT or grad student, 5600 or #; 4 lect hrs per wk)
Masonry materials and their production, mortars and grouts, design of nonreinforced and reinforced masonry structural systems, walls, columns, lintels, arches. Codes and specifications, testing, and inspection.

Construction Materials

CE 5701. BITUMINOUS MATERIALS I. (4 cr; prereq upper div IT or grad student, 5603; 3 lect, 3 lab hrs per wk) Physical and chemical properties and characteristics of bituminous binders and aggregates. Properties and design of bituminous mixtures and surface treatments.

CE 5702. COMPONENTS, PROPERTIES, AND DESIGN OF PORTLAND CEMENT CONCRETE. (4 cr; prereq upper div IT or grad student, 5603; 3 lect, 3 lab hrs per wk) Physical and chemical properties and characteristics of portland cement, aggregates, and admixtures. Properties and design of concrete mixtures.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

CE 8022. NUMERICAL METHODS FOR FREE AND MOVING BOUNDARY PROBLEMS

CE 8097-8098-8099. CIVIL ENGINEERING RESEARCH

CE 8200. THEORY OF TRAFFIC FLOW

CE 8201. URBAN TRAFFIC OPERATIONS

CE 8210. MODELING CONSUMER CHOICES IN TRANSPORTATION

CE 8211. TRAVEL DEMAND FORECASTING

CE 8212. AUTOMATIC INCIDENT DETECTION

CE 8214. TRANSPORTATION SYSTEMS DYNAMICS AND CONTROL

CE 8302. SOIL/ROCK PLASTICITY AND LIMIT ANALYSIS

CE 8321. MECHANICS OF GRANULAR MEDIA

CE 8322. STORAGE AND FLOW OF GRANULAR MATERIAL

CE 8360. ENGINEERING MODEL FITTING

CE 8401. INTRODUCTION TO ENVIRONMENTAL BOUNDARY LAYER THEORY

CE 8402. INTRODUCTION TO THE THEORY AND MEASUREMENT OF TURBULENT FLOWS

CE 8407. STOCHASTIC HYDROLOGY

CE 8408. SPECIAL TOPICS IN HYDROLOGY

CE 8413. MECHANICS OF SEDIMENT TRANSPORT

CE 8415. HYDROPOWER DEVELOPMENT

CE 8418. COMPUTATIONAL HYDRODYNAMICS I

CE 8419. COMPUTATIONAL HYDRODYNAMICS II

CE 8425. ADVANCED GROUNDWATER MECHANICS I

CE 8426 ADVANCED GROUNDWATER MECHANICS II

CE 8430. LAKE AND RESERVOIR HYDRODYNAMICS

CE 8435. SPECIAL TOPICS IN HYDRODYNAMIC THEORY

CE 8440. FLOW EFFECTS ON STRUCTURES

CE 8500. PHYSICAL AND CHEMICAL PROCESSES FOR WATER AND WASTEWATER TREATMENT I

CE 8501. PHYSICAL AND CHEMICAL PROCESSES FOR WATER AND WASTEWATER TREATMENT II

CE 8502. BIOLOGICAL AND CHEMICAL PROCESSES FOR WASTEWATER TREATMENT

CE 8505, 8506. AQUATIC CHEMISTRY FOR ENVIRONMENTAL ENGINEERS

CE 8507. ENVIRONMENTAL PROCESSING OF ORGANIC MATERIALS

CE 8540. INTERFACIAL MASS TRANSFER WITH ENVIRONMENTAL APPLICATIONS

CE 8550. ANALYSIS AND MODELING OF AQUATIC ENVIRONMENTS

CE 8551. SEMINAR ON MODELS OF AQUATIC ENVIRONMENTS

CE 8605. THE FINITE ELEMENT METHOD IN CIVIL ENGINEERING

CE 8606. APPROXIMATE METHODS OF STRUCTURAL ANALYSIS

CE 8608. ADVANCED THEORY OF STRUCTURES

CE 8609. PRINCIPLES OF STRUCTURAL STABILITY

CE 8610. SHELL STRUCTURES

CE 8611. PLATE STRUCTURES

CE 8612. PLASTIC DESIGN OF STEEL STRUCTURES

CE 8616. NONLINEAR STRUCTURAL SYSTEMS

CE 8618. RELIABILITY IN STRUCTURAL ENGINEERING

CE 8620-8621. STRUCTURAL DYNAMICS I-II

CE 8625. BEHAVIOR OF REINFORCED CONCRETE STRUCTURES I

CE 8690. STRUCTURES: SPECIAL TOPICS

CE 8697-8698-8699. SEMINAR: STRUCTURES

Computer Science (CSci)

CSci 1001. INTRODUCTION TO COMPUTERS FOR NON-COMPUTER SCIENCE MAJORS. (4 cr; no degree cr for IT students)
History and societal impact of computers; legal and ethical issues in computer usage; basic computer organization; concept of an algorithm; flowcharting; understanding of and hands-on experience with software packages ranging from editing and word processing to symbolic mathematics.

CSci 3101. INTRODUCTION TO COMPUTER APPLICATIONS FOR SCIENTISTS AND ENGINEERS. (4 cr; prereq first-qtr calculus; informal lab)
Algorithm development and principles of computer programming using FORTRAN, emphasizing numerical methods for science and engineering applications. Integral nonscheduled lab.

CSci 3102. INTRODUCTION TO PASCAL PROGRAMMING. (4 cr; prereq non-CSci major, pre-calculus or #; informal lab)
PASCAL computer language, applications, programming techniques. Designed to bring students to advanced-level competence in PASCAL programming. Integral nonscheduled lab.

CSci 3113. INTRODUCTION TO PROGRAMMING IN C. (4 cr; prereq precalculus or #; not for cr after taking 3121 or 3321 or 5113)
Students use the C language to write several programs that illustrate flow control, basic data types (array, record, pointer), and program structuring. Prepares students for more advanced courses in data structures and algorithms.

CSci 3121. SURVEY OF DATA STRUCTURES AND ALGORITHMS. (4 cr, §3105, §3321; prereq knowledge of C or 3113 or #)
Fundamental data structures and rudimentary computer algorithms. Students implement these data structures and their operations as abstract data types. Study of C++ with emphasis on implementation of data types and control structures.

CSci 3204H. INTRODUCTION TO PROGRAMMING AND PROBLEM SOLVING IN SCIENCE AND ENGINEERING I. (2 cr; prereq Honors Calc I, IT Honors Program)
Problem solving and algorithms. Computer use in text editing, spread sheets, use of menus. Introduction to PASCAL: sequence and I/O, decision and iteration. Programming with integers and characters. Iteration and recursion. Systematic loop design, loop invariants, introduction to loop design theory. Concept of array. Programming with real numbers. Input and computational errors. Use of PASCAL library.

CSci 3205H. INTRODUCTION TO PROGRAMMING AND PROBLEM SOLVING IN SCIENCE AND ENGINEERING II. (2 cr; prereq 3204H, Honors Calculus II, IT Honors Program)
Introduction to C++ programming: sequence, iteration, decision, functions, pointers, arrays. Searching and sorting as examples of complexity study. Organization of larger programs. Concept of abstract data type and its implementation using C++ classes.

CSci 3311. DISCRETE STRUCTURES OF COMPUTER SCIENCE. (4 cr, §3400; prereq 3117, 3321)
Mathematical techniques and structures in computer science. Formal logic, elementary combinatorics, induction, recurrences, relations and graphs.

CSci 3316. STRUCTURE OF COMPUTER PROGRAMMING I. (4 cr, §3106; prereq 1 qtr calculus or #)
Different programming paradigms as a formal way of expressing computer algorithms and data. Procedures, recursion, and iteration as algorithmic development techniques. Use of abstraction and modularity. Scheme language used for illustrating ideas and lab problems.

CSci 3317. STRUCTURE OF COMPUTER PROGRAMMING II. (4 cr; prereq 3316)
Advanced programming paradigms. Object-oriented programming, logic programming, and pattern matching illustrated with examples. Generic operators, local variables, and objects as ways of encapsulating different conceptual parts of a program. Language scheme used to illustrate ideas and lab problems.

CSci 3321. ALGORITHMS AND DATA STRUCTURES I. (4 cr, §3105, §3121; prereq knowledge of C or 3113 or #)
Fundamental data structures with some of the rudimentary computer algorithms. Students implement these data structures and their operations as abstract data types. Study of C++ with emphasis on implementation of data types and control structures.

CSci 3322. ALGORITHMS AND DATA STRUCTURES II. (4 cr, §5121; prereq 3311, 3321)
Fundamental paradigms for algorithm design with the supporting data structures. Complexity, correctness analysis, and lower bound theory. Implementation of selected algorithms and data structures using C++.

CSci 3327. INTRODUCTION TO THE ORGANIZATION OF COMPUTER SYSTEMS. (4 cr, §3107, §5101; prereq 3316 or 3121 or ¶3321 or #)
Organization of hardware and software systems that support computer programming and program execution. Symbolic assembly language used to study the mapping of application programs and data into the underlying hardware. Ideas illustrated in assembly language programs (currently Motorola 680x0).

CSci 5090. HISTORY OF COMPUTING. (4 cr, §HSci 5321)
Developments in the last century: factors affecting evolution of hardware and software, growth of the industry and its relation to other business areas, changing relationships resulting from new data-gathering and analysis techniques.

CSci 5101. INTRODUCTION TO THE ORGANIZATION OF COMPUTER SYSTEMS. (4 cr, §3107, §3327; prereq 3121 or 3316, non-CSci major or #; informal lab)
Organization of hardware and software systems that support computer programming and program execution. Symbolic assembly language used to study the mapping of application programs and data into the underlying hardware. Ideas illustrated in assembly language programs (currently Motorola 680x0).

CSci 5102. INTRODUCTION TO SYSTEMS PROGRAMMING. (4 cr; prereq 3327 or 5101 or #; informal lab; does not carry grad cr for CSci majors)
User-level programming view of operating system functions. Introduction to UNIX systems programming. Use of system calls, relationships between C library functions and systems calls, file systems, process management functions, input-output, signal handling, use of pipes and sockets, shell programming.

CSci 5103. INTRODUCTION TO OPERATING SYSTEMS. (4 cr; §5502; prereq 3322, 5102, 5201 or #; informal lab)
Concepts used in operating system designs and implementations. Relationships between operating system structures and underlying machine architectures. UNIX implementation mechanisms presented as examples.

CSci 5104. SYSTEM SIMULATION: LANGUAGES AND TECHNIQUES. (4 cr; prereq 3327 or 5101, Stat 3091 or #; informal lab)
Methodologies relevant to system modeling and simulation. Application of stochastic processes, Markov chains, and queuing theory to developing system models and simulation experiments. Data collection and statistical analysis of output. Fundamentals of discrete event-based simulations using digital computers. Discussion of simulation languages, both process- and event-oriented, including SIMULA and SIMPAS. Applications of these techniques to job shops, operations research, and modeling of computer and communications systems.

CSci 5106. STRUCTURE OF HIGHER-LEVEL LANGUAGES. (4 cr; prereq 3317, 3321, 3327, or #; informal lab; does not carry grad cr for CSci majors)
Motivation, syntax and semantics, imperative languages (e.g., Ada, C), type system, control structures, procedures, activation record model, exception handlers; encapsulation, parameterization; functional languages (e.g., Lisp, Scheme, ML or FP); object-oriented languages (e.g., Smalltalk, C++ or CLOS); trends (e.g., concurrent model).

CSci 5107. COMPUTER GRAPHICS I. (4 cr; prereq 3322, 3327 or #; informal lab)
Students do extensive programming and learn theoretical underpinnings of computer graphics. General graphics issues, user interface issues, 2D graphics, introduction to 3D graphics (including 3D pipeline, shading and hidden surface removal, and ray tracing).

CSci 5110. USER INTERFACE DESIGN, IMPLEMENTATION, AND EVALUATION. (4 cr; prereq 3322, 3327 or #; informal lab)
Students work in groups on a course-long project that includes designing, prototyping, implementing, and evaluating an application interface. User testing and non-user walkthrough and heuristic techniques.

CSci 5111. GUI TOOLKITS AND THEIR IMPLEMENTATION. (4 cr; prereq 5107 or 5110 or #; informal lab)
Structure and design of user interface toolkits and frameworks. Includes window system protocols, toolkit design, event processing, data management and constraints, geometry management, resource managements, and other features of advanced interface development toolkits. Students complete a project in which they implement a toolkit extension or widget.

CSci 5113. INTRODUCTION TO OBJECT-ORIENTED PROGRAMMING USING C++. (4 cr; prereq background in C programming equiv to 3113; not for cr after taking 3121 or 3321)
For students who already know how to program in C. Inheritance, including polymorphism and multiple inheritance. Container classes and iterators. Operator overloading, user-defined implicit conversions, constructors, destructors, and templates.

CSci 5117. COMPUTER GRAPHICS II. (4 cr; prereq 5107 or #; informal lab)
Spline curves and surfaces, and other advanced modeling techniques, solid modeling, color theory, advanced shading algorithms, advanced ray tracing, radiosity, introduction to scientific visualization.

CSci 5121. ALGORITHMS AND DATA STRUCTURES II. (4 cr, §3322; prereq 3311 or #)
Fundamental paradigms for algorithm design with the supporting data structures. Complexity, correctness analysis, and lower bound theory. Implementation of selected algorithms and data structures using C++.

CSci 5122. ADVANCED DATA STRUCTURES. (4 cr; prereq 3322 or 5121 or #; informal lab)
Internal and external sorting, symbol tables, optimal binary search trees, AVL trees, hashing, B-trees, tries, files and indexes, ISAM, multilists, inverted files, cellular partitions, differential files.

CSci 5151. INTRODUCTION TO PARALLEL COMPUTING. (4 cr; prereq 3121 or 3322 or #)
Programming techniques, algorithms, data structures. Evaluation of algorithm quality. Effectiveness and scalability. Basic concepts and algorithms for parallel computation.

CSci 5161. INTRODUCTION TO COMPILERS. (4 cr, §5504; prereq 5106 or #; informal lab)
Techniques for implementing programming languages. Compiler front end, recognizing syntactic structures, generating internal representations. Symbol table manipulation and type checking.

CSci 5180. SOFTWARE ENGINEERING I. (4 cr; prereq 5106 or #; informal lab)
Software life cycle, requirement acquisition, specification, design, coding, and testing. Criteria for requirement acquisition, object-oriented analysis and modeling, structures analysis, process description. Techniques for specification verification and validation, completeness and consistency, and multilevel checking. Formal analysis of semiformal specifications. Object-oriented design techniques and patterns. Current software development and application environments. Software prototyping, maintenance, and application issues. Students participate in a group project to develop an application from user requirements.

CSci 5181. SOFTWARE ENGINEERING II. (5 cr; prereq 5180; scheduled lab)
Requirement analysis. Project planning and management. Design reviews, software testing, validation strategies. Maintenance. Lab with group projects, 12 hours per week project work outside class. Selected projects on the process of systems development, from requirements analysis through maintenance. Student groups will specify, design, implement, and test partial software systems. Emphasis on application of general software development methods and principles from 5180, rather than on specific systems.

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

CSci 5201. COMPUTER ARCHITECTURE. (4 cr; prereq 3311, 3327 or #; informal lab)
Elementary computer architecture, gates and digital logic, register transfers and micro-operations, processor studies of existing systems.

CSci 5211. DATA COMMUNICATIONS AND COMPUTER NETWORKS. (4 cr; prereq 5102 or #; informal lab)
Network classification and services. Hardware components: multiplexers, concentrators, communications media. Network protocols and architectures. Research areas.

CSci 5280. COMPUTER-AIDED DESIGN. (4 cr; prereq 3311 or #; informal lab)
CAD for digital systems with emphasis on VLSI. Hardware description languages: synthesis, simulation, test generation.

CSci 5281. COMPUTER-AIDED DESIGN OF VLSI. (4 cr; prereq 3311 or #; informal lab)
CAD for digital systems with emphasis on VLSI. Physical design: partitioning, placement and routing, design and electrical rule checks. Inherent complexity of algorithms. Analysis of best known algorithms.

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

CSci 5301. NUMERICAL COMPUTATION. (4 cr; prereq Math 3261, knowledge of a programming language or #)
Floating point arithmetic and rounding errors. Iterative methods. Numerical solution of nonlinear equations. Newton's method. Direct methods for linear systems of equations. Gaussian elimination. Factorization methods. Interpolation and approximation. Numerical integration and differentiation. Introduction to numerical solution of ordinary differential equations.

CSci 5302. ANALYSIS OF NUMERICAL ALGORITHMS. (4 cr; prereq 5301 or #)
Norms, condition numbers and error analysis. Convergence rates for iterative methods. Numerical approximation methods. Least squares. Fast Fourier transform. Gaussian quadrature. Spline interpolation. Computation of eigenvalues and eigenvectors. Stability and error analysis of methods for ordinary differential equations.

CSci 5304. COMPUTATIONAL ASPECTS OF MATRIX THEORY. (4 cr; prereq 5302 or #; informal lab)
Direct and iterative solution of large linear systems. Decomposition methods. Computation of eigenvalues and eigenvectors. Singular value decomposition. Linpack and other software packages. Methods for sparse and large structured matrices.

CSci 5305. NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS. (4 cr; prereq 5302 or #; informal lab)
Initial value problem. Convergence and stability. Efficient implementation. Error estimation and step size control. Comparison of recent software packages. Two-point boundary value problems. Collocation and finite element methods.

CSci 5306. NUMERICAL METHODS FOR PARTIAL DIFFERENTIAL EQUATIONS. (4 cr; prereq 5302, differential equations or advanced calculus or #)
Fundamentals of partial differential equations. Finite difference and finite element discretization methods. Numerical treatment of parabolic, hyperbolic, and elliptic problems. Convergence, stability, and consistency. Iterative methods. Programming techniques and use of FORTRAN packages.

CSci 5320. INTRODUCTION TO LINEAR PROGRAMMING. (4 cr, §5001; prereq 5301 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; commercially available LP systems; methods for large, sparse systems. Interior methods for LP.

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

CSci 5400. INTRODUCTION TO AUTOMATA THEORY. (4 cr; prereq 3311 or #)
Turing machines, computable functions, unsolvability of the halting problem, recursive functions. Finite state models; equivalence, minimization, properties, decision questions, characterizations. Regular expressions. Survey of other automata.

CSci 5421. INTRODUCTION TO ALGORITHM DESIGN. (4 cr, §8401; prereq 3322, 5121 or #; informal lab)
Divide-and-conquer, dynamic programming, the greedy method, matroids, backtracking and branch-and-bound, basic graph algorithms, techniques for geometric problems, string matching.

CSci 5422. ADVANCED DATA STRUCTURES. (4 cr, §5122; prereq 5421 or #; informal lab)
Advanced techniques for representing and manipulating data efficiently and analyzing the performance of these methods. Priority queues, balanced search trees, multidimensional searching structures, amortized complexity and its applications to data structure design, persistent data structures, data structures for secondary storage.

CSci 5442. INTRODUCTION TO COMPUTATIONAL GEOMETRY. (4 cr; prereq 5421 or #)
Techniques for designing and analyzing geometric algorithms. Geometric problems that occur naturally in various applications such as computer graphifcs, solid modeling, CSD, robotics, manufacturing, and vision. "Pure" and "applied" aspects of geometric computation.

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

CSci 5511. ARTIFICIAL INTELLIGENCE I. (4 cr; prereq 3322 or #; informal lab)
Introduction to ideas and issues of artificial intelligence. Knowledge representation, problem solving, search, inference techniques, theorem proving. Expert systems. Introduction to applications. Programming languages.

CSci 5512. ARTIFICIAL INTELLIGENCE II. (4 cr; prereq 5511 or #; informal lab)
Techniques of artificial intelligence to solve complex problems. Natural language processing and speech recognition. Machine perception and integrated robots. Planning. Machine learning. Expert systems.

CSci 5521. PATTERN RECOGNITION. (4 cr; prereq 5301, 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.

CSci 5531. ARTIFICIAL INTELLIGENCE PROGRAMMING TECHNIQUES. (4 cr; prereq 5511 or #; informal lab)
Languages and programming techniques for problems in artificial intelligence. Lisp and Prolog. Production system and frame-based languages. High-level tools. Implementation of knowledge representation structures and inference operations. Applications in expert systems.

CSci 5551. INTRODUCTION TO INTELLIGENT ROBOTIC SYSTEMS. (4 cr; prereq 5511 or #)
Fundamentals of operations of a robot manipulator. Overview of sensing techniques and introduction to their basic principles. Real-time programming issues as applied to the control of a robot. Robot programming and planning.

CSci 5561. COMPUTER VISION. (4 cr; prereq 5511 or #)
Representational and computational tools. Matching. Edge detection. Shape from shading, motion, and stereo. Texture. Object recognition. Applications.

CSci 5571. EXPERT SYSTEMS. (4 cr; prereq 5511 or #)
Introduction to expert systems. Aspects of artificial intelligence representations and inferencing mechanisms as they apply to expert systems. Students develop a small expert system.

CSci 5599. PROBLEMS: ARTIFICIAL INTELLIGENCE. (1-4 cr [may be repeated for cr]; prereq #)
Special courses or individual study arranged with faculty member.

CSci 5702. THE PRINCIPLES OF DATABASE SYSTEMS. (4 cr; prereq 3322 or #; informal lab)
Fundamental concepts. Conceptual data organization. Data models. Data manipulation languages. Database design. Security and integrity. Performance evaluation. Query optimization. Distributed database systems.

CSci 5703. DATABASE SYSTEM DESIGN. (4 cr; prereq 5702 or #; informal lab)
Application of database concepts in the design and development of database systems and database applications. Design of current commercial and research-oriented database systems. Techniques of using database systems for applications.

CSci 5705. OBJECT-ORIENTED DATABASES. (4 cr; prereq 5702 or #)
Applications and motivation; extended relational, object-relational, and object-oriented data models; object identifier, types and constructors; versions and schema evolution; query language (e.g. recursion, path expressions); object indices, buffer management and other implementation issues; triggers, rules, complex objects, case studies.

CSci 5799. PROBLEMS IN INFORMATION SCIENCE. (1-4 cr[may be repeated for cr]; prereq #)
Special course or individual study arranged with faculty member.

CSci 5863. COMPUTER SYSTEMS PERFORMANCE ANALYSIS. (4 cr, §EE 5863; prereq 5201 or EE 5858, grad IT major or #)
Tools and techniques for measuring and analyzing computer hardware, software, and system performance. Benchmark programs, measurement tools, performance metrics. Presenting data, summarizing measured data, comparing system performance. Deterministic and probabilistic simulation techniques, random number generation and testing. Bottleneck analysis.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

CSci 8101. ADVANCED OPERATING SYSTEMS

CSci 8102. OPERATING SYSTEMS THEORY

CSci 8103. DISTRIBUTED AND PARALLEL PROGRAMMING

CSci 8199. SEMINAR: LANGUAGES AND SYSTEMS

CSci 8299. SEMINAR: MACHINE DESIGN

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

CSci 8307. ADVANCED PARALLEL NUMERICAL METHODS

CSci 8314. ITERATIVE METHODS FOR LINEAR SYSTEMS

CSci 8320. NUMERICAL SOLUTION OF LINEAR LEAST SQUARES PROBLEMS

CSci 8330. PARALLEL METHODS FOR NUMERICAL OPTIMIZATION

CSci 8399. SEMINAR: NUMERICAL ANALYSIS

CSci 8402. ALGORITHMS—TECHNIQUES AND THEORY

CSci 8403-8404. THEORY OF COMPUTATION

CSci 8499. SEMINAR: COMPUTATIONAL THEORY AND LOGIC

CSci 8505. OPTIMIZATION IN COMPILERS

CSci 8511. SPECIAL CONCEPTS IN ARTIFICIAL INTELLIGENCE

CSci 8521. NEUROCOMPUTING AND NEURAL NETWORKS

CSci 8551. ARTIFICIAL INTELLIGENCE TECHNIQUES IN ROBOTICS

CSci 8561. READINGS IN COMPUTATIONAL VISION

CSci 8571. READINGS IN EXPERT SYSTEMS

CSci 8581. READINGS IN PARALLEL SYMBOLIC COMPUTING

CSci 8599. SEMINAR: ARTIFICIAL INTELLIGENCE

CSci 8699. SEMINAR: CONTROL SCIENCE

CSci 8701. ADVANCED TOPICS IN DATA BASE SYSTEMS

CSci 8799. SEMINAR: INFORMATION SCIENCE

CSci 8899. COLLOQUIUM: COMPUTER SCIENCE

Electrical Engineering (EE)

EE 1000. INTRODUCTION TO ELECTRICAL ENGINEERING. (1 cr; prereq lower div IT or Δ; S-N only)
Introduction to electrical engineering presented by practicing engineers and members of the faculty.

EE 1400. CIRCUITS LABORATORY. (1 cr; prereq IT student, 3009 or ¶3009)
Lab to accompany 3009 and 3010.

EE 3005. ELECTRONIC CIRCUITS AND SYSTEMS. (4 cr; not for EE majors; prereq IT student, 3009)
Fundamentals of analog, digital, and power systems. Operational amplifiers, semiconductor devices, transistor amplifying circuits. Introduction to digital logic concepts. Digital circuits and systems. Power devices and electromechanical drives.

EE 3006. CIRCUITS AND ELECTRONICS LABORATORY. (1 cr; not for EE majors; prereq IT student, 3005 or ¶3005)

EE 3009. LINEAR CIRCUITS I. (4 cr; prereq IT student, Math 3261 or ¶Math 3261, Phys 1253 or ¶Phys 1253)
Physical principles underlying the modeling of circuit elements. Two- and three-terminal resistive elements, Kirchhoff's laws. Independent and dependent sources, op-amps. Simple resistive circuits. Linearity in circuits. First- and second-order circuits. Circuits in sinusoidal steady state.

EE 3010. LINEAR CIRCUITS II. (4 cr; prereq IT student, at least C grade in 3009, Math 3261, Phys 1253 or ¶Phys 1253)
Energy and power in AC circuits. Transformers. Laplace transform techniques of circuit analysis. Frequency response, Bode graphs. Two ports.

EE 3011. SIGNAL ANALYSIS. (4 cr; prereq upper div EE major; 3010)
Fourier methods of analysis. Laplace transforms and applications. Z-transforms. Frequency and time-domain responses.

EE 3012. SYSTEM DESIGN. (4 cr; prereq upper div EE major, 3011)
Continuous, discrete-time systems. Feedback: stability, applications.

EE 3021. PROBABILITY IN ENGINEERING SYSTEMS. (4 cr; prereq upper div EE major, 3011)
Notions of probability. Elementary data analysis. Random variables, densities, expectation, correlation. Random processes in linear systems, spectral analysis. Computer experiments in analysis and design in a random environment.

EE 3060. SEMICONDUCTOR DEVICES. (4 cr; prereq upper div IT, 3010 or ¶3010, Phys 3501)
Elementary semiconductor physics; physical description of pn junction diodes, bipolar junction transistors, and field-effect transistors.

EE 3061. ANALOG ELECTRONICS. (4 cr; prereq upper div IT, 3010, 3060, 3400 or ¶3400)
Small signal models for the BJT and FET. Elementary amplifiers. Differential and operational amplifiers; applications.

EE 3062. ANALOG AND DIGITAL ELECTRONICS. (4 cr; prereq upper div IT, 3061, 3351, 3401 or ¶3401)
Stability and feedback amplifiers, operational amplifier structures; implementation of digital circuits with bipolar and field-effect transistors; application to inverters, gates, flip-flops, logic arrays, and storage elements.

EE 3110. ELECTRIC AND MAGNETIC FIELDS. (4 cr; prereq upper div IT, Phys 3501, Math 3252 or ¶Math 3252)
Field properties of electricity and magnetism. Interaction with dielectric and magnetic materials.

EE 3111. ELECTROMAGNETIC WAVES. (4 cr; prereq upper div EE, 3110)
Time-varying electromagnetic fields. Propagation and reflection of electromagnetic waves. Metallic and optical waveguides.

EE 3351. INTRODUCTION TO LOGIC DESIGN. (4 cr; prereq IT soph or jr or sr)
Boolean algebra and logic gates. Combinational logic: simplification and design examples. Sequential logic and design of synchronous sequential logic systems. Integral lab.

EE 3352. INTRODUCTION TO MICROPROCESSORS. (4 cr; prereq IT soph, CSci 3113)
Basic computer organization and assembly language programming. Instruction types and addressing modes. Subroutines. Assembler usage. Programming techniques. Integral lab.

EE 3400-3401-3402. JUNIOR ELECTRICAL ENGINEERING LABORATORY. (2 cr per qtr; prereq EE major, 1400, 3060 or ¶3060 for 3400, 3061 or ¶3061 for 3401, 3062 or ¶3062 for 3402)
Experiments in circuits, electronics, and electromagnetic fields.

EE 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.

EE 3476-3477. INDUSTRIAL ASSIGNMENT I-II. (2 cr; prereq regis in co-op program)
Industrial work assignment in engineering co-op program. Grade based on student's formal written report covering quarter's work assignment but deferred until completion of EE 5478.

EE 5002. DIGITAL SIGNAL PROCESSING. (3 cr; prereq upper div EE or grad IT major, 3012 or #)
General concepts of signal processing; discrete-time systems and digital filters.

EE 5003. DIGITAL SIGNAL PROCESSING LABORATORY. (1 cr; prereq upper div EE, 3402 or ¶3402, 5002 or #)
Computer experiments in digital signal processing and digital filter design.

EE 5053. DESIGN OF DIGITAL CIRCUITS. (3 cr; prereq upper div EE or grad IT major, 3062 or #)
Design of modern digital integrated circuits at subsystem level. Nonlinear device models used to predict system performance. Comparison of performance and topology of various logic families including TTL, MOS, CMOS, I2L, and ECL.

EE 5055. INSTRUMENTATION AND CONTROL ELECTRONICS. (4 cr; prereq upper div EE or grad IT major, 3012 or ¶3012, 3062 or #)
Characteristics of operational amplifiers; applications of operational amplifiers including A-D and D-A converters; compensation of operational amplifiers; power amplifiers; semiconductor controlled rectifiers, applications; linear and switching voltage regulators.

EE 5056. ELECTRONIC CIRCUITS LABORATORY. (1 cr; prereq IT student or grad IT major, 3402 or ¶3402, ¶5055)

EE 5090. DIGITAL CIRCUIT DESIGN LABORATORY. (1 cr; prereq 3402 or ¶3402, ¶5053)

EE 5151. MATERIALS AND DEVICES I. (4 cr; prereq IT student or grad IT major, 3062, 3111, Phys 3501 or #)
Fundamental electronic properties of materials with emphasis on semiconductors. Carrier transport and statistics. Diodes, BJT's, and lasers.

EE 5161. MATERIALS AND DEVICES II. (4 cr; prereq 5151 or #)
Introduction to fundamental physical properties of structures, dielectric, and magnetic systems. Metal semiconductor contacts, MOS structures, fiber optics, superconductors.

EE 5162. SOLID-STATE TRANSDUCERS. (3 cr; prereq IT student or grad IT major, 3060, 3111, Phys 3501 or #)
Design and operation of solid state devices used for transducing physical and chemical signals.

EE 5202. ANALOG COMMUNICATION. (3 cr; prereq upper div EE or grad IT major, 3012, Stat 3091 or #)
Selected topics in analog communication systems: amplitude and frequency modulation; spectral analysis and effect of noise in modulation systems; detection.

EE 5203. INTRODUCTION TO DIGITAL COMMUNICATION. (3 cr; prereq upper div EE or grad IT major, 3012, 5202, Stat 3091 or #)
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.

EE 5240. ANALOG COMMUNICATIONS LABORATORY. (1 cr; prereq EE sr or grad IT major, 3402 or ¶3402, ¶5202)

EE 5241. DIGITAL COMMUNICATIONS LABORATORY. (1 cr; prereq EE sr or grad IT major, 3402 or ¶3402, ¶5203)

EE 5253. LINEAR CONTROL SYSTEMS. (3 cr; prereq upper div EE or grad IT major, 3012 or #)
Modeling, characteristics, and performance of feedback control systems. Stability, root-locus and frequency-response methods. Compensator design.

EE 5255. DIGITAL CONTROL SYSTEMS. (3 cr; prereq upper div EE or grad IT major, 3351, 3352 or equiv, 5002 or ¶5002, 5253 or #)
Time- and frequency-domain analysis of discrete-time and digital control systems. Data conversion and interfacing. Digital computers as control system components. Software and hardware considerations in digital control system design.

EE 5290. DIGITAL CONTROL SYSTEMS LABORATORY. (1 cr; prereq upper div EE, 5291, ¶5255)

EE 5291. LINEAR CONTROL SYSTEMS LABORATORY. (1 cr; prereq EE sr or grad IT major, 3402 or ¶3402, ¶5253)

EE 5300. ELECTROMECHANICS. (4 cr; upper div EE or grad IT major, 3011, 3110)
Principles of electromechanical energy conversion with applications to actuators, transducers, and rotating machines. Performance characteristics derived from analytical models of AC and DC machines.

EE 5310. ELECTRIC POWER SYSTEMS. (4 cr; prereq IT student or grad IT major, 3402 or ¶3402, 5300 or #)
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.

EE 5315. ELECTROMECHANICS IN ROBOTICS. (3 cr; prereq upper div EE, 3012, 5300 or #)
Modeling of mechanical system elements. Sensors and encoders for speed and position control. Mathematical modeling and control of DC-, "brushless" DC-, induction-, and stepper-motors in incremental motion systems. Torsional resonances and optimum design in high performance systems. Design examples.

EE 5322. ELECTROMECHANICAL PROCESSES AND DEVICES. (4 cr; prereq IT student or grad IT major, 3402 or ¶3402, 5300 or #)
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.

EE 5355. MICROPROCESSOR INTERFACING AND SYSTEM DESIGN. (4 cr; prereq upper div EE or grad IT major, 3351, 3352, 3402 or ¶3402 or #)
Microprocessor interfacing. Memory design. Exception handling. Parallel and serial input/output: techniques and devices. Bus arbitration control and multimaster systems. Direct memory access. Designing dynamic RAM memory systems. Memory management. Integral lab.

EE 5358. DIGITAL DESIGN WITH PROGRAMMABLE LOGIC. (4 cr; prereq EE upper div or grad IT major or adult spec, 3351, 3352)
Overview of advanced digital design using programmable devices. Designing viable projects using Montor Graphics ECAD tools and Xilinx field programmable gate arrays.

EE 5450. SENIOR DESIGN PROJECT. (2 cr [may be repeated for cr]; prereq EE sr, 3012, 3062, 3110, 3351, 3352, 3402)
Team participation in formulating and solving open-ended design problems. Oral and written presentations.

EE 5470. DIRECTED STUDY. (Cr ar [may be repeated for cr]; prereq Δ)
Studies of approved topics, theoretical or experimental in nature.

EE 5478-5479. INDUSTRIAL ASSIGNMENT III-IV. (2 cr per qtr; prereq 3477, regis in co-op program)
Industrial work assignment in engineering co-op program. Grade based on student's formal written report covering the quarter's work assignment.

EE 5490H-5491H-5492H HONORS PROJECT. (3 cr per qtr; prereq Δ)
Design project for students in electrical engineering honors program.

For Graduate Students and Qualified Seniors

EE 5505. ANALOG INTEGRATED CIRCUIT DESIGN. (3 cr; prereq grad standing or #)
Review of MOS fabrication technology and device-level models. Basic equations and higher-order effects. Noise. Basic CMOS building blocks: current mirrors, differential pairs, transconductance amplifiers. Unbuffered operational amplifiers: single-stage, Miller-compensated, folded-cascade. Output stages and comparators.

EE 5506. ANALOG CIRCUITS FOR SIGNAL PROCESSING. (3 cr; prereq 5505 or grad standing or #)
Review of filter types and Laplace and Fourier transforms; time and frequency-domain concepts; approximation methods (e.g., Butterworth, Chebyshev); frequency transformations. Ideal and non-ideal operational amplifiers, switched-capacitor filters; biquads and higher-order filters. Switched-capacitor gain stages, rectifiers and oscillators.

EE 5511. DIGITAL FILTERING AND SIGNAL PROCESSING. (3 cr; prereq grad IT major, 5002 or #)
Review of theory of linear shift-invariant, discrete-time systems (z-transform, discrete time Fourier transform, sampling, discrete Fourier transform). Interpolation and decimation. The fast Fourier transform and fast convolution. Finite impulse response filter design approaches and techniques. Infinite impulse response filter design approaches and techniques; quantization.

EE 5512. ADAPTIVE DIGITAL FILTER THEORY. (3 cr; prereq grad IT major, 5511, 5702 or #)
Review of partial characterization of discrete-time random processes and correlation matrix eigenstructure. Auto regressive modeling: FIR Wiener filter theory; linear squares; LMS algorithm (transient and steady-state behavior); RLS algorithm; lattice structure.

EE 5513. MULTISCALE AND MULTIRATE SIGNAL PROCESSING. (3 cr; prereq grad IT major, 5511, 5702 or #)
Discrete-time linear systems, sampling of continuous and discrete-time signals. Multirate discrete-time systems. Bases and frames. Continuous wavelet transforms. Scaling equations. Discrete wavelet transform. Applications in signal and image processing.

EE 5514. REAL-TIME DIGITAL SIGNAL PROCESSING LABORATORY. (2 cr; prereq EE sr or IT grad or adult spec, 3352, 5511 or #)
Real-time computation of digital signal processing functions, including filtering, sample-rate change, and differential pulse code modulation. Implementation of a current digital signal processing chip. Study of the chip architecture, assembly language, and arithmetic. Consideration of real-time processing issues, including data quantization, limiting and scaling, processor limitations, and I/O handling.

EE 5515. FAST FOURIER TRANSFORM AND CONVOLUTION ALGORITHMS. (3 cr; prereq 5002 or #)
Theory and implementation of fast algorithms for discrete Fourier transform and convolution, including one- and multi-dimensional cases.

EE 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 hazards. Experiments in neural and muscle stimulation, EKG and EMG recording, neuron simulation, filtering and low-noise amplifiers.

EE 5561. MAGNETISM: PHYSICS, GEOPHYSICS, AND ENGINEERING. (3 cr, §Geo 5561, §Phys 5561; prereq Phys 1253)
Elementary statistical mechanics, rock magnetism, micromagnetic modeling. Applications of magnetism in geophysics, biomagnetism, magnetic sensors, and recording.

EE 5571. VLSI DESIGN I. (3 cr; prereq grad standing in EE, CSci or Phys or #)
CMOS switch model, stick diagrams, restoring logic, and steering circuits. Process flows, layout design rules, and latch-up avoidance. Parasitic resistance and capacitance, delay models, design optimization, and worst-case design. Dynamic circuit techniques, including precharging, Domino CMOS, multiplephase clocking, charge sharing, clock generation, and synchronization failure. Subsystem design, including multiplexers, registers, decoders, PLAs, finite state machines, adders, and function units.

EE 5572. VLSI DESIGN II. (3 cr; prereq 5571 or #)
Design methodologies, switch-level simulation, symbolic layout, and compaction. CMOS fault models, scan design, signature analysis, and built-in test. Computational unit design, including arithmetic-logic units, counters, fast multipliers, and barrel shifters. Memory architectures, RAM and ROM cells, sense amplifiers, content-addressable memory, and hardware stack. VLSI system case studies.

EE 5573. VLSI DESIGN III. (3 cr; prereq 5572 or #)
Register files, busing structures, pipelining, and fine-grained parallelism. Control structures based on random logic. PLAs and ROMs. Multi-level control schemes and microsequencer design. RISC architectures, including overlapped register windows, delayed branching, pipeline interlocks, and hardware-software tradeoffs. Memory management units and cache design. VLSI system case studies.

EE 5574-5575†. COMPUTER-AIDED VLSI DESIGN LABORATORY. (3 cr per qtr; prereq IT sr or grad IT major or IT adult spec or #, 5571 or ¶5571 for 5574, 5572 or ¶5572 for 5575)
Creative use of design aids in parameter extraction, schematic capture, chip layout, channel-routing, maze-routing, multi-level simulation, and artwork verification. Complete design of integrated circuits in MOS and bipolar technologies. Designs evaluated by computer simulation.

EE 5576. VLSI MODELING AND PROCESSING. (3 cr; prereq 5572 or #)
Advanced modeling and processing; arithmetic considerations. Algorithmically specialized processors: locality, pipelining, interconnection patterns. Special algorithms for signal processing, finite element problems, tree search (optimization).

EE 5604. INTRODUCTION TO MICROWAVE ENGINEERING. (3 cr; prereq EE sr or grad IT major, 3111 or equiv)
Review: Maxwell's equations, wave equation, transmission lines. Circuit theory of waveguiding systems. Transmission lines and lumped elements—conventional and planar structures. Impedance transformation and matching. Passive devices. Resonators. Filters.

EE 5605. MICROWAVE DEVICES AND CIRCUIT APPLICATIONS. (3 cr; prereq 3111, 5604 or equiv or #)
Two-terminal devices including varactors, p-i-n diodes, step-recovery diodes, Gunn devices, and Impatt diodes for device physics and circuit applications as detectors, mixers, frequency converters, amplifiers, and oscillators. Three-terminal devices including FETs, heterostructure biopolar transistors, device physics, and circuit applications in amplifiers, oscillators, mixers, and frequency converters.

EE 5606. ANTENNA THEORY AND DESIGN. (3 cr; prereq 3111 or #)
Fundamentals of antenna design for transmission and reception at radio and microwave frequencies. Antenna analysis techniques. Antenna applications including linear, loop, microstrip, aperture, and traveling wave antennas; broadband antennas and antenna arrays.

EE 5625. FOURIER OPTICS. (4 cr; prereq 3011, 3111 or #)
Fourier analysis of optical systems and images with applications to spatial filtering, optical information processing, and holography. Fresnel and Fraunhofer diffraction. Current topics such as speckle interferometry, hybrid (optical- digital) information processing systems, and computer-generated holograms.

EE 5630. CONTEMPORARY OPTICS. (4 cr; prereq 3111 or Phys 5024 or #)
Fundamentals of lasers, including propagation of Gaussian beams, optical resonators, theory of laser oscillation, electro-optic and acoustic modulation, and nonlinear optics.

EE 5631. PHOTONIC DEVICES. (3 cr; prereq EE sr or grad IT major, 5630 or 5661)
Photonic devices including optical properties of semiconductors, light-emitting diodes, lasers, and photodetectors.

EE 5634. PHYSICAL OPTICS: APPLICATIONS AND TECHNIQUES. (3 cr; prereq 5625 or #)
Applications of interference, diffraction and polarization in optical systems. Diffractive optical elements and microlenses. Volume diffraction in color and reflection holograms. Interferometry in astronomy and spectroscopy. Optical pattern recognition and optical computing.

EE 5635. OPTICAL SYSTEM DESIGN. (3 cr; prereq IT sr or grad IT major)
Elementary or paraxial optics. Non-paraxial, exact-ray tracing. Energy considerations in instrument design. Fourier optics and image quality. Design examples: telescopes, microscopes, diffraction-limited lenses, projectors, scientific instruments.

EE 5636. OPTICAL FIBER COMMUNICATION. (3 cr; prereq 3011, 3111 or #)
Components and systems aspects of optical fiber communication. Modes of optical fibers. Signal degradation and dispersion. Optical sources and detectors. Digital and analog transmission systems. Direct detection and coherent detection.

EE 5637. PHYSICAL OPTICS LABORATORY. (3 cr; prereq 5625 or #)
Fundamental optical techniques, diffraction, optical pattern recognition, spatial and temporal coherence, speckle; interferometry, coherent and incoherent imaging, coherent image processing, fiber optics. Includes lab experiments at local industries.

EE 5650. PHYSICAL METHODS IN SOLID STATE MATERIALS I. (3 cr; prereq EE sr or grad or adult spec, 3111)
Basic concepts in classical and statistical mechanics relevant to the properties of solid state materials. Hamiltonian dynamics, statistical ensembles, phase space, partition function, classical and quantum statistics, relation between statistical mechanics and thermodynamics, Boltzmann transport theory.

EE 5651. PHYSICAL METHODS IN SOLID STATE MATERIALS II. (3 cr; prereq EE sr or grad or adult spec, 5650 or #)
Applying quantum theory to solid state materials. Schrödinger's equation, one-dimensional problems, angular momentum, central forces, scattering, spin, atomic and chemical structure. Crystal structure in solids, lattice vibrations and phonons, energy bands.

EE 5652. PHYSICAL METHODS IN SOLID STATE MATERIALS III. (3 cr; prereq EE sr or grad or adult spec, 5651 or #)
Physical properties of solid state materials. Properties of insulators and doped semiconductors, transport and scattering in semiconductors, Hall and thermal effects, quasi-Fermi levels, generation and recombination. Conduction in metals, superconductivity. Magnetic properties of materials. Amorphous materials.

EE 5661. SEMICONDUCTOR PROPERTIES AND DEVICES I. (3 cr; prereq EE sr or grad or adult spec, 3111, 5650 or #)
Principles and properties of semiconductor devices. Selected topics in semiconductor materials, statistics, and transport. Aspects of transport in p-n junctions, heterojunctions.

EE 5662. SEMICONDUCTOR PROPERTIES AND DEVICES II. (3 cr; prereq EE sr or grad or adult spec, 5661 or #)
Principles and properties of semiconductor devices. Charge control in different FETs, transport, modeling. Bipolar transistor models (Ebers-Moll, Gummel-Poon), heterostructure bipolar transistors. Special devices.

EE 5666-5667. 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.

EE 5669. MAGNETIC RECORDING. (3 cr; prereq EE sr or grad or adult spec)
Review of fundamental magnetic concepts relevant to magnetic recording. Introduction to basic models of longitudinal and perpendicular magnetic recording and reproduction processes. Comparison of design, fabrication, and performance of conventional and thin film heads, tapes, disks, and recording systems.

EE 5670. BASIC MICROELECTRONICS. (3 cr; 5670-5672†; prereq EE sr or grad or adult spec)
Experimental and theoretical studies of the basic physical processes used in microelectronic device fabrication. Transistor and integrated circuit layout, fabrication, and evaluation.

EE 5672. BASIC MICROELECTRONICS LABORATORY. (1 cr; 5670-5672†; prereq IT sr or grad or adult spec, 5670 or ¶5670)
Students fabricate a polysilicon gate, single-layer metal NMOS chip, performing about 80 percent of processing, including photolithography, diffusion, oxidation, and etching. In-process measurement results compared with final electrical test results. Simple circuits used to estimate technology performance.

EE 5673. ADVANCED MICROELECTRONICS. (2 cr; prereq IT sr or grad or adult spec, 5670, 5672 or ¶5672 or #)
Integration of unit processes into a fabrication technology; physics and chemistry of advanced techniques such as molecular beam epitaxy, electron beam lithography, and reactive ion etching.

EE 5680. PRINCIPLES OF THIN FILM TECHNOLOGY. (4 cr; prereq IT sr or grad IT major)
Introduction to principles of fabrication, characterization, and processing of thin films for engineering applications. High-vacuum systems, thin film deposition techniques, energetics and kinetics of thin film formation, and electrical, dielectric, magnetic, optical, and piezoelectric properties of thin films. Lab.

EE 5700. INFORMATION THEORY AND CODING. (3 cr; prereq IT sr or grad or adult spec, Stat 3091 or #)
Discrete information sources and channels, source encoding, the binary channel and Shannon's theorem. Block codes for the binary channel.

EE 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.

EE 5704. DIGITAL COMMUNICATION. (3 cr; prereq upper div EE or grad IT major, 5203, Stat 3091 or #)
Theory and techniques of modern digital communication; channel capacity; modulation and detection; data transmission over channels with large intersymbol interference; optimal and suboptimal sequence detection; equalization; error correction coding; trellis-coded modulation.

EE 5712. KALMAN FILTERING AND APPLICATIONS. (3 cr; prereq 5702, Stat 3091, grad standing or #)
Mathematical description of random signals; response of linear systems to random inputs. Discrete Kalman filter; applications. Continuous Kalman filter; smoothing; nonlinear extensions.

EE 5750. TOPICS IN LINEAR SYSTEMS. (3 cr; prereq grad standing, Math 5242 or #)
State variable and input/output models of linear systems. Controllability, observability, stability, minimality, and structure. State variable feedback and observers.

EE 5751. LINEAR OPTIMAL CONTROL. (3 cr; prereq grad standing, 5750, Math 5243 or ¶Math 5243 or #)
Time- and frequency-domain models of multiple-input-multiple-output systems. Linear-quadratic and linear-quadratic-Gaussian problems. Properties of linear-quadratic and linear-quadratic-Gaussian regulators. Output feedback and separation theorem.

EE 5752. COMPUTER-AIDED DESIGN OF CONTROL SYSTEMS. (3 cr; prereq grad standing, 5751 or #)
Development of control-system-design problem. Frequency response techniques in design of single-input-single-output and multiple-input-multiple-output control systems. Robust control concepts. Computer-aided-design tools, application in design of single-input-single-output and multiple-input-multiple-output control systems with robust performance.

EE 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.

EE 5802. ELECTRIC POWER SYSTEM ANALYSIS. (3 cr; prereq IT sr or grad or adult spec, 3010, 5300, 5310 or #)
Formulating equations for describing electric power networks. Advanced computer methods for large-scale electric power systems. Application to the power-flow, faulted system calculations, and stability studies.

EE 5803-5804. POWER GENERATION, OPERATION, AND CONTROL. (3 cr each; prereq IT sr or grad or adult spec, 3010, 5300, 5310, 5802 or #)
Economic dispatch of generation units, transmission system loss models, unit scheduling via dynamic programming and Lagrange relaxation algorithms, fuel and hydro scheduling via linear programming and transportation algorithms, energy production-costing algorithms, evaluation of energy transactions between suppliers, energy management systems, real-time control of generating units, system security evaluation, state estimation techniques, optimal power flow algorithms.

EE 5805. ELECTRIC POWER SYSTEM ENGINEERING. (3 cr; prereq IT sr or grad adult spec, 3010, 5300, 5310 or #)
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.

EE 5807. POWER SYSTEM PROTECTION. (3 cr; prereq IT sr or grad or adult spec, 3010, 5300, 5310 or #)
Fundamentals of fault condition calculations, modern power system circuit breakers, interrupt devices. Sensing transducers for input to protection relays, differential principle, time-overcurrent protection; directional and distance sensing, backup protection. System grounding principles, generator protection, transformer, reactor and shunt capacitor protection. Bus and line protection.

EE 5814. SWITCHED MODE POWER ELECTRONICS. (3 cr; prereq IT sr or IT grad standing or IT adult spec, 3061, 3402 or #)
Overview of power capabilities and switching speeds of power semiconductor devices. Generic converter topologies and regulation techniques. Application and design of generic circuits such as switching power supplies, inverter devices for motors, battery chargers, uninterruptible power supplies, wind/photovoltaic inverters.

EE 5815. SWITCHED MODE POWER ELECTRONICS II. (3 cr; prereq IT sr or grad or IT adult spec, 5814 or #)
Limitations and methods of increasing power capabilities of switching devices. Device physics, switching characteristics, gate/base drives, stress reduction and loss considerations in using devices such as BJTs, MOSFETs, Gate-Turn-Off Thyristors. Future developments. Passive components and circuit layout in switched mode power electronics.

EE 5816. SWITCHED MODE POWER ELECTRONICS LABORATORY. (2 cr; prereq IT sr or IT grad standing or IT adult spec, ¶5815 or #)
Switching characteristics of power semiconductor devices. Gate/base drives and snubbers. DC to DC converter circuits. Design and control of a switching power supply. Drives for dc-, induction-, "brushless" dc-, and stepper-motors. Battery chargers and uninterruptible power supplies. Other residential and industrial application.

EE 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.

EE 5825. FINITE-ELEMENT METHODS IN ELECTRICAL ENGINEERING. (3 cr; prereq EE sr or IT grad, #)
Finite-element methods for solving electromagnetic field problems. Electric circuit approach to finite-element analysis. Engineering applications selected from two-dimensional problems in electrostatics, magnetostatics, and electric conduction. Computer implementation.

EE 5851. APPLIED SWITCHING THEORY. (3 cr; prereq 3351, 3352 or #)
Review of traditional logic design methods. Algorithm machine method. Synthesis of sequential synchronous and asynchronous machines. Synthesis by programmable devices. Linear sequential circuits. Von Neumann architectures. A register transfer language. Hardware description in RTL.

EE 5852-5853. COMPUTER ORGANIZATION AND DESIGN I-II. (3 cr per qtr; prereq 3351, 3352, ¶5851, 5852 for 5853)
Digital computer organization; register-level simulation; control unit design; microprogramming; memory organization. Input/output techniques; arithmetic unit design. Features of larger computers.

EE 5854. ADVANCED COMPUTER NETWORKS. (3 cr; prereq grad IT major or EE adult spec, CSci 5211 or #)
International Standards Organization (ISO) network architecture. Topology analysis. Data communication. Satellite and packet radio networks. Distributed systems and case studies.

EE 5858. COMPUTER ARCHITECTURE. (3 cr; prereq IT sr or IT grad standing or IT adult spec, 5853 or #)
Conventional and unconventional uniprocessor system design options. Impact of software on system architecture. Instruction set selection and architectural consequences. Memory systems including segmentation, paging, and cache memories. Control unit design. Object manipulation structures. Examples from current and historically important designs.

EE 5860. MICROCOMPUTER ARCHITECTURE. (4 cr; prereq IT grad, 5355 or #)
Advanced microprocessor organization, 16- and 32-bit microprocessors, microprocessor bus structures, exception processing, interrupts, and virtual memory. Coprocessor organizations and multiprocessor systems. Design for testability. Integral lab.

EE 5863. COMPUTER SYSTEMS PERFORMANCE ANALYSIS. (3 cr; prereq IT grad, 5858 or #)
Tools and techniques for measuring and analyzing computer hardware, software, and system performance. Benchmark programs, measurement tools, performance metrics. Presenting data, summarizing measured data, comparing system performance. Deterministic and probabilistic simulation techniques, random number generation and testing. Bottleneck analysis.

EE 5865. CODING TECHNIQUES AND APPLICATIONS. (3 cr; prereq grad IT major or #)
Linear error detecting/correcting codes, application to computers, polynomial description of codes, cyclic codes, encoder and decoder circuits, application to magnetic tapes, random test vector generation for self-test, signature analysis for data compression.

EE 5874. SIMULATION AND TEST IN DIGITAL DESIGN. (3 cr; prereq IT sr or grad or adult spec, 5851, CSci 3113 or equiv)
Theory and practice of simulation and test generation algorithms in digital design.

EE 5952. SPECIAL TOPICS IN ELECTRICAL ENGINEERING. (1-3 cr [may be repeated for cr]; prereq IT grad student or adult spec or #)
Topics vary.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

EE 8060. ADVANCED BIPOLAR TRANSISTOR THEORY

EE 8090. ELECTRONICS SEMINAR

EE 8100-8101. ADVANCED ENGINEERING ELECTROMAGNETICS

EE 8110-8111. PLASMA PHYSICS

EE 8120-8121-8122. FUNDAMENTALS OF ACOUSTICS

EE 8140. SEMINAR: PLASMA PHYSICS

EE 8143. SEMINAR: MODERN OPTICS

EE 8153-8154. PROPERTIES OF SEMICONDUCTORS

EE 8160. QUANTUM ELECTRONICS I

EE 8164. QUANTUM ELECTRONICS II (GUIDED WAVE OPTICS)

EE 8170. FLUCTUATION PHENOMENA

EE 8180. ADVANCED ANALOG INTEGRATED CIRCUITS

EE 8181. ADVANCED DIGITAL INTEGRATED CIRCUITS

EE 8190. SEMINAR: QUANTUM ELECTRONICS

EE 8191. SEMINAR: SURFACE PHYSICS

EE 8192. SEMINAR: MAGNETICS

EE 8203-8204. SIGNAL DETECTION AND ESTIMATION THEORY WITH APPLICATIONS

EE 8205. IMAGE PROCESSING AND APPLICATIONS

EE 8207. VLSI SIGNAL PROCESSING

EE 8211. CODING THEORY

EE 8220. TOPICS IN STATISTICAL THEORY OF COMMUNICATION

EE 8240. SEMINAR: COMMUNICATION

EE 8250-8251-8252. ADVANCED CONTROL TOPICS

EE 8257, 8258. ADVANCED SYSTEMS THEORY I, II

EE 8260. TOPICS IN NONLINEAR SYSTEMS

EE 8290. SEMINAR: CONTROL THEORY

EE 8291. SEMINAR: SYSTEM THEORY

EE 8300-8301. ADVANCED POWER SYSTEM TOPICS

EE 8305. SPARSE MATRIX METHODS IN POWER SYSTEM ANALYSIS

EE 8340. SEMINAR: ELECTRIC POWER

EE 8342. POWER ELECTRONICS: UTILITY APPLICATIONS

EE 8352. FAULT DIAGNOSIS AND RELIABLE DESIGN

EE 8353. SEQUENTIAL CIRCUIT THEORY

EE 8359. COMPUTING WITH NEURAL NETWORKS

EE 8362. ADVANCED COMPUTER ARCHITECTURE

EE 8363-8364. PARALLEL PROCESSING I-II

EE 8370. DESIGN OF INTELLIGENT SYSTEMS

EE 8390. COMPUTER SYSTEMS SEMINAR

EE 8450. SPECIAL INVESTIGATIONS

EE 8451. ADVANCED TOPICS IN ELECTRICAL ENGINEERING

EE 8460. PLAN B PROJECT

EE 8461. PLAN B PROJECT

EE 8490, 8491, 8492. GRADUATE SEMINAR

Extractive Metallurgical Engineering (MetE)

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

MetE 8000-8001. APPLIED PROCESS METALLURGY I-II

MetE 8401-8402-8403. SEMINAR IN METALLURGICAL ENGINEERING

MetE 8830. ELECTRIC AND MAGNETIC SEPARATION OF MINERALS

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

MetE 8842. SURFACE CHEMISTRY OF MINERAL SUSPENSIONS

MetE 8921-8922-8923. RESEARCH IN EXTRACTIVE METALLURGICAL ENGINEERING

MetE 8930-8932-8934. PHYSICAL CHEMISTRY OF HIGH TEMPERATURE METALLURGICAL REACTIONS I-II-III

Geological Engineering (GeoE)

GeoE 5218. DESIGN OF UNDERGROUND EXCAVATIONS IN ROCK. (4 cr, §CE 5305; prereq IT or grad student, 5302 or #)
Stresses and deformations around underground excavations in rock. Design of linings and support systems. Excavation by boring, drill, and blast. Tunneling under adverse conditions. Materials handling and tunnel ventilation.

GeoE 5260. DRILLING, BLASTING, AND COMMINUTION. (4 cr; prereq IT or grad student, CE 3300 or #)
Rock excavation and size reduction by drilling, blasting, and comminution; basic mechanics of fracture; bit penetration into rock; properties of explosives; strain wave transmission, reflection and refraction in drilling and blasting; design of blasting rounds; tunnel boring machines. Types of crushing and grinding equipment and their selection.

GeoE 5262. GEOLOGICAL ENGINEERING ANALYSIS. (4 cr; prereq IT sr or grad IT major 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.

GeoE 5302. APPLIED ROCK MECHANICS. (4 cr; prereq IT student or grad IT major, 3300)
Site investigations; rock mass classifications. In-situ stress. Behavior of intact rock. Shear strength of joints; rock mass behavior. Stereographic projections; kinematic analysis of rock slopes. Foundations on rock.

GeoE 5437. COMPUTER APPLICATIONS IN GEOLOGICAL ENGINEERING. (4 cr, §CE 5021; prereq upper div CE or GeoE, CE 3020, Math 3251, Math 3252 or #)
Three methods (finite differences, finite elements, boundary elements) for solution of problems in hydrology, structural engineering, geomechanics, and environmental engineering that reduce to partial differential equations. Each method illustrated in context of practical problems.

GeoE 5555. ENGINEERING GEOSTATISTICS. (4 cr, §CE 5055; prereq sr or grad in CE or Geo or GeoE, Stat 3091 or #)
Problem solving and decision making in geological engineering using the tools of applied statistics. Emphasis on spatially correlated data, e.g., geologic site characterization, rock mass parameter estimation, ore body modeling, optimal sample design for groundwater contamination assessment.

GeoE 5660-5661-5662. SPECIAL GEOLOGICAL ENGINEERING PROBLEMS. (Cr and hrs ar; prereq IT sr or #)
Literature survey, research work, or design study in geological engineering problems.

GeoE 5700. SYSTEMS ANALYSIS FOR GEOLOGICAL ENGINEERS. (4 cr; prereq upper div IT or grad student)
Introduction to systems analysis and decision making; expert systems; operations research techniques, modeling, and simulation. Applications in geological engineering and related fields.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

GeoE 8302. SOIL/ROCK PLASTICITY AND LIMIT ANALYSIS

GeoE 8336. BOUNDARY ELEMENT METHODS I

GeoE 8350. ADVANCED ROCK MECHANICS I-II

GeoE 8360. ENGINEERING MODEL FITTING

GeoE 8601-8602-8603. SEMINAR: GEOLOGICAL ENGINEERING

GeoE 8612-8613-8614. RESEARCH PROBLEMS

Geology and Geophysics (Geo)

Geo 1001f,w,s,su. THE DYNAMIC EARTH: AN INTRODUCTION TO GEOLOGY. (4 cr; 4 lect hrs per wk) Staff
Nonmathematical introduction to Earth: its internal structure; processes that shape its surface; theory of plate tectonics; action of streams, glaciers, waves, wind, and groundwater; limnology; fossil fuels and mineral deposits; environmental geology; planetary geology; and the geology of Minnesota.

Geo 1002w,s. HISTORICAL GEOLOGY. (4 cr; 3 lect, one 2-hr lab hrs per wk) Sloan
Evolution of Earth from its origin; the succession of physical and biological events of past 600 million years.

Geo 1003f,s. DINOSAURS AND THEIR WORLD. (4 cr) Kirkby
Dinosaurs and the Mesozoic Era; plate tectonics, evolution, extinction, global change.

Geo 1005w. GEOLOGIC PERSPECTIVES ON ENERGY. (4 cr; 4 lect hrs per wk) Alexander
Introduction to the geologic aspects of energy resources, conventional and unconventional. History of energy use, distribution and amounts of known and potential reserves, environmental aspects and implications of U.S. consumption patterns.

Geo 1011s. VOLCANOES OF THE EARTH. (4 cr; 4 lect hrs per wk) Stout
Nonmathematical introduction to volcanoes, their origin and distribution on Earth and through time; theory of plate tectonics, origin of magmas and the Earth's interior, products of volcanoes, types of eruptions and hazards, and impact on climate, vegetation, and society.

Geo 1012f. PLANET EARTH. (4 cr) Murthy
Nonmathematical introduction to planet Earth. Relationships among various Earth systems—solid Earth, hydrosphere, atmosphere; various natural cycles that control the way the planet works and how human interactions disturb these cycles and their rates.

Geo 1019s. OUR CHANGING PLANET. (4 cr, §Ast 1019, §EEB 1019) Murthy, staff
Interrelationships among Earth's subsystems—solid Earth, oceans, atmosphere, biosphere—and solar and galactic super-systems. Interactions of the natural cycles, their rates and feedbacks, and human impacts.

Geo 1021f,w,s,su. INTRODUCTION TO GEOLOGY LAB: GEOLOGY OF MINNESOTA. (1 cr; prereq 1001 or ¶1001 or #; one 2-hr lab per wk) Staff
Ten lab exercises based on the geology of Minnesota. Introduction to the bedrock, glacial history, topography, mineral resources, and environmental geology of the state through use of appropriate minerals, rocks, topographic and geological maps.

Geo 1601w. OCEANOGRAPHY. (4 cr; 3 lect, 1 lab hrs per wk) Barnwell, Paola
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.

Geo 1602CEE. ALL ABOUT LAKES: THEIR ORIGINS, BEHAVIOR, AND MANAGEMENT. (4 cr) Staff
Origin of lakes, their response to solar radiation and wind, unique flora and fauna that exist in lakes, and the effects of these organisms on the chemistry of lake waters and vice versa. Human impact on lakes, current methods of lake restoration and management.

Geo 3111su. INTRODUCTORY FIELD GEOLOGY. (4 cr; prereq 3202, #) Staff
Geologic mapping on topographic maps and aerial photos; field identification of igneous, sedimentary, and metamorphic rocks; measurement of stratigraphic sections; study of structural and geomorphic features.

Geo 3201. GEODYNAMICS I: THE SOLID EARTH. (4 cr; prereq Phys 1251, 1252) Moskowitz, Stout
Introduction to the dynamics of the solid Earth, particularly the tectonic system.

Geo 3202. GEODYNAMICS II: THE FLUID EARTH. (4 cr; prereq 3201) D Kohlstedt, Paola
Introduction to the dynamics of the fluid Earth, mainly surface processes and convection.

Geo 3211Hs. HONORS EARTH SCIENCE. (4 cr, §1001, §1021; prereq selection for IT honors curriculum or consent of IT Honors Office; 4 lect, 1 rec hrs per wk) Staff
Applications of physics and chemistry to the Earth's structure and dynamics.

Geo 3301. GEOCHEMICAL PRINCIPLES. (4 cr; prereq Chem 1051, 1052) Seyfried, Stout
Introduction to the Earth's chemistry.

Geo 3401w. INTRODUCTORY MINERALOGY. (4 cr, §5004; prereq 1001, Chem 1051, Math 1252 or #; 3 lect, 4 lab hrs per wk) Staff
Crystallography, crystal chemistry, and crystal physics. Physical and chemical properties, crystal structures, and chemical equilibria of the major mineral groups. Lab includes crystallographic, polarizing microscope, X-ray powder diffraction exercises, and hand-specimen mineral identification.

Geo 3402s. PETROLOGY. (4 cr; prereq 3401 or #) Edwards, Weiblen
Introduction to lithologic character and genesis of igneous and metamorphic rocks.

Geo 3990. PROBLEMS IN GEOLOGY. (1-6 cr; prereq #. Δ) Research or problem selected on basis of individual interests and background.

Geo 5004w. MINERALOGY. (4 cr, §3401; prereq Chem 1051, Math 1252 or #; 3 lect, 4 lab hrs per wk) Staff
See Geo 3401.

Geo 5010. FIELD WORKSHOP. (2 cr; prereq Geo or Geophys or GeoE major or #) Staff
Geologic or geophysical field study.

Geo 5020. LABORATORY WORKSHOP. (2 cr; prereq Geo or Geophys or GeoE major or #) Staff
Geologic or geophysical lab study.

Geo 5030. MODELING WORKSHOP. (2 cr; prereq Geo or Geophys or GeoE major or #) Staff
Modeling of geologic or geophysical systems.

Geo 5051su,CEE. PHYSICAL GEOLOGY FOR TEACHERS. (4 cr, §1001/1021; prereq educ degree, 1 term college chemistry or physics)
Introduction to scientific methods and nature of the Earth; main features of the physical world and the processes that have formed them.

Geo 5052su,CEE. HISTORICAL GEOLOGY FOR TEACHERS. (4 cr, §1002; prereq educ degree, 1001 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. Lab, fieldwork, and seminar.

Geo 5053CEE. ALL ABOUT LAKES FOR TEACHERS. (4 cr, §1602; prereq educ degree) Staff
Origin of lakes, their response to solar radiation and wind, unique flora and fauna that exist in lakes, and the effects of these organisms on the chemistry of lake waters and vice versa. Human impact on lakes, current methods of lake restoration and management.

Geo 5054CEE. INTRODUCTION TO THE MESOZOIC FOR TEACHERS. (4 cr, §1003; prereq educ degree) Kirkby
Dinosaurs and the Mesozoic Era; plate tectonics, evolution, extinction, global change. Students design modules to present course material to elementary or secondary school students.

Geo 5101. GEOCHRONOLOGY AND STRATIGRAPHY. (4 cr; prereq 3301) Staff
Methods for measuring geologic time and dating rocks, both relatively and absolutely; correlation and other stratigraphic techniques.

Geo 5108w. ADVANCED ENVIRONMENTAL GEOLOGY. (4 cr; prereq Geo core courses through 5201 or equiv or #) Pfannkuch
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. Field project.

Geo 5111su. ADVANCED FIELD GEOLOGY. (4 cr; prereq 3111, #)
Geologic mapping; study of igneous, metamorphic, and sedimentary rocks; structures and surficial features; problem solving. Paper required.

Geo 5112su. FIELD HYDROGEOLOGY. (4 cr; prereq 5641, #) Staff
Aquifer, vadoze zone, and surface water hydrology field techniques. Shallow soil boring and sampling. Well installation. Single and multiple well aquifer testing. Groundwater sampling for chemical analysis. Weather data collection, hydrogeologic mapping, water balance calculation.

Geo 5151f. INTRODUCTION TO PALEONTOLOGY. (5 cr; prereq 1002 or #) Sloan
Morphology, classification, and ecology of selected major fossil groups.

Geo 5154w. VERTEBRATE PALEONTOLOGY I. (5 cr; prereq 5151 or EEB 5114) Sloan
Morphology, evolution, and stratigraphic distribution of fossil fish, amphibians, reptiles, and birds.

Geo 5155s. VERTEBRATE PALEONTOLOGY II. (5 cr; prereq 5154 or EEB 5114) Sloan
Morphology, evolution, and stratigraphic distribution of fossil mammals.

Geo 5201s. STRUCTURAL GEOLOGY. (4 cr; prereq 3402, 5101 or #) Teyssier
Deformation of the Earth's crust. Processes associated with deformation, faulting, folding, and fabric development; labs and recitations include solving problems and conducting physical and numerical experiments; field trips offered.

Geo 5202. TECTONIC STYLES. (3 cr; prereq 5201 or #; 3 lect hrs per wk; offered alt yrs) Hudleston
Origin and nature of major types of disturbances affecting the continental crust, including analysis of the form and development of individual structural components.

Geo 5203w. GEOTECTONICS. (3 cr; prereq 5201 or #; offered alt yrs) Teyssier
Problems associated with global tectonics; structure and evolution of the Earth's crust and lithosphere; study of active compressional, extensional, and wrench tectonic regimes, with many examples from various parts of the world; interpretation of older tectonic systems.

Geo 5251s. GEOMORPHOLOGY. (4 cr [5 cr with term project]; prereq 1001, Math 1031 or #; 3 lect, 2 lab hrs per wk, lab often used for field trips) Hooke
Origin, development, and continuing evolution of landforms in various environments. Environmental implications emphasized. Weathering, slope and shore processes, fluvial erosion and deposition, wind action, tectonics, and impact phenomena.

Geo 5252w. REGIONAL GEOMORPHOLOGY. (3 cr; prereq 5201 or #; offered alt yrs) Hooke
Geology of a particular region of the country and its geomorphology. One-week field trip to the area late in the quarter.

Geo 5255w. GLACIOLOGY. (4 cr [5 cr with term project]; prereq Math 3261 or #) Hooke
Theories of glacier flow. Internal structures and heat flow in glaciers and ice sheets. Reading assignments and problems.

Geo 5261f. GLACIAL GEOLOGY. (4 cr [5 cr with term paper or map lab]; prereq 1002 or #)
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.

Geo 5311. GEOCHEMICAL PROCESSES. (4 cr; prereq 3301, Chem 5520 or #) Ito, Seyfried
Processes pertaining to distribution and control (structural, thermodynamic, kinetic) of chemical species in Earth and hydrosphere.

Geo 5313. AQUEOUS GEOCHEMISTRY. (4 cr; prereq 5311, Chem 5520 or #) Seyfried
General principles of solution chemistry with application to geology including solution-mineral equilibria, redox processes in natural waters, and geochemistry of hydrothermal fluids.

Geo 5321. ISOTOPE GEOLOGY. (4 cr; prereq 3301 or #; offered alt yrs) Alexander, Ito
Introduction to theory and uses of radioactive, radiogenic, and stable isotopes in geology. Radioactive dating, geothermometry, and tracer techniques in geologic processes.

Geo 5405. OPTICAL MINERALOGY. (2 cr; prereq 3401 or ¶3401) Staff
Optical properties of minerals; symmetry and crystal optics; identifying minerals using the polarizing microscope.

Geo 5452s. IGNEOUS AND METAMORPHIC PETROLOGY. (5 cr; prereq 3402, Chem 5520, Math 3261 or #) Stout
Theoretical course that develops basic thermodynamic tools and chemographic analysis for the interpretation of chemical processes in igneous and metamorphic rocks. Lab, field trip, problem sets, term paper.

Geo 5501w. GEOPHYSICAL METHODS IN GEOLOGY. (4 cr; prereq upper div IT or CLA jr or sr, 3402, Phys 1253 or #) Staff
Geophysical properties of the Earth and Earth materials, internal structure and constitution, geophysical exploration methods and geologic interpretation, radioactivity and thermal structure of the Earth, physical basis for plate tectonics.

Geo 5505f. SOLID-EARTH GEOPHYSICS I. (4 cr; prereq 3201, Phys 1253)
Elasticity, seismology; physical structure of the Earth's crust and deep interior.

Geo 5506w. SOLID-EARTH GEOPHYSICS II. (4 cr; prereq 3201, Phys 1253) Staff
Earth's gravity fields; mantle viscosity, paleomagnetism, seismic tomography, basic mantle convection and thermal history.

Geo 5507s. SOLID-EARTH GEOPHYSICS III. (4 cr; prereq 3201, Phys 1253) D Kohlstedt
Mechanical properties and transport processes in Earth materials with emphasis on their importance to a range of geophysical phenomena.

Geo 5508. MINERAL AND ROCK RHEOLOGY. (4 cr; prereq 3201, Phys 1253) Karato
Elastic, anelastic, and viscous deformation of minerals and rocks. Materials science fundamentals and geological/geophysical applications.

Geo 5515w. PRINCIPLES OF GEOPHYSICAL EXPLORATION. (4 cr; prereq Phys 1253) Staff
Seismic exploration (reflection and refraction), potential techniques (gravity and magnetics), and electrical techniques of geophysical exploration.

Geo 5522. TIMES-SERIES ANALYSIS OF GEOLOGICAL PHENOMENA. (4 cr; prereq Math 3221 or #; offered alt yrs)
Linear and nonlinear geological and geophysical phenomena: ice age cycles, earthquakes, climatic fluctuations, volcanic eruptions, atmospheric phenomena, thermal convection and other time-dependent natural phenomena; nonlinear dynamics and complexity theory.

Geo 5535w. GEOLOGICAL THERMOMECHANICAL MODELING. (4 cr; prereq Math 3261 or #; offered alt yrs) Yuen
Concept of heat and mass transfer processes in the Earth's crust and mantle. Quantitative study of thermomechanical phenomena. Emphasis on both analytical and modern numerical techniques.

Geo 5536s. APPLICATIONS OF FLUID MECHANICS TO GEOLOGICAL PROBLEMS. (4 cr; prereq 1 yr calculus, AEM 3200 or CE 3400 or #; offered alt yrs) Yuen
Scaling equations for geological approximations, applications to geological situations, rheology.

Geo 5541f. GEOMAGNETISM. (4 cr; prereq 3201, Math 1251, Phys 1251 or #)Banerjee
Present geomagnetic field at the Earth's surface and at the core-mantle boundary, secular variation, paleointensity variation, geomagnetic field reversal, models for field transition.

Geo 5543. PALEOMAGNETISM. (4 cr; prereq 3201, Math 1251, Phys 1251 or #) Moskowitz
Physical and chemical basis of paleomagnetism. Origin of natural remanent magnetization and its stability, mineralogy of magnetic minerals, paleomagnetic measurement techniques, statistics of paleomagnetic data, magnetic polarity stratigraphy, apparent polar wander, environmental magnetism.

Geo 5561s. MAGNETISM: PHYSICS, GEOPHYSICS, AND ENGINEERING. (3 cr, §EE 5561, §Phys 5561; prereq Phys 1251; offered alt yrs) Moskowitz
Elementary statistical mechanics, rock magnetism, micromagnetic modeling. Applications of magnetism in geophysics, biomagnetism, magnetic sensors, and recording.

Geo 5601f. LIMNOLOGY. (4 cr, §EEB 5601; prereq Chem 1052 or equiv)
Events occurring in lakes, reservoirs, and ponds, from their origins through the study of their physics, chemistry, and biology. Emphasis on interrelationships of these parameters and on effects of civilization on lakes.

Geo 5603. GEOLOGICAL LIMNOLOGY. (4 cr; prereq 5601 or EEB 5601)
Tectonic and climatic setting of lakes; physical, chemical, and biological processes of sedimentation in lakes.

Geo 5613f. KARST HYDROGEOLOGY AND TRACER APPLICATIONS. (4 cr; prereq 5641, #; offered alt yrs) Alexander, Pfannkuch
Karst hydrogeology and application of tracers to determine the source, age, and mixing parameters of water in various natural reservoirs. Physical and chemical principles and processes operating in karst hydrogeology and the use of natural and synthetic chemical and isotopic labels or tracers to follow the movement and mixing of water through the hydrologic cycle.

Geo 5621. LIMNOLOGY LABORATORY. (2 cr, §EEB 5621; prereq 5601 or EEB 5601 or #)
Lab to accompany Geo 5601 (EEB 5601). Techniques for obtaining information about conditions in lakes and streams. Procedures for measuring abundance and population dynamics of aquatic organisms, with emphasis on plankton. Field instruments, sampling devices, chemical analyses, microscopy, and analysis of data. One Saturday field trip.

Geo 5631s. EARTH-SYSTEM : GEOSPHERE/ BIOSPHERE INTERACTIONS. (4 cr, §EEB 5004; prereq 3202, 3301 or #) Kelts
Interdisciplinary study of global change forcing mechanisms, feedbacks, and dynamics on various time scales using paleorecord to illustrate processes.

Geo 5641f. GENERAL AND PHYSICAL HYDROGEOLOGY. (4 cr; prereq 1001, Chem 1052, Math 1252, Phys 1105, Geo major core curriculum through 3402 or #) Pfannkuch
Theory of groundwater geology, hydrologic cycle, watershed hydrology, Darcy's law, governing equations of groundwater motion, flow net analysis, analog models, groundwater resource evaluation and development.

Geo 5642s. QUANTITATIVE HYDROGEOLOGY. (4 cr; prereq 1001, Chem 1052, Math 1252, Phys 1105, Geo major core curriculum through 3402 or #) Person
Applied analysis of steady and transient equations of groundwater motion and chemical transport using analytical and numerical methods. Numerical flow net analysis, well hydraulics, salt-water intrusion problems, unsaturated flow.

Geo 5643w. CHEMICAL HYDROGEOLOGY. (4 cr; prereq 1001, Chem 1052, Math 1252, Phys 1105, Geo major core curriculum through 3402 or #) Alexander
Chemistry of natural waters, acid-base and redox reactions, carbonate equilibria, contaminant hydrology, isotope hydrology, chemical modeling.

Geo 5651. SEDIMENTOLOGY. (4 cr; prereq 3402, upper div IT major in Geo or Geophys or GeoE or MinE or CLA jr or sr Geo major or #) Paola
Interpretation of origin of sedimentary rocks through application of basic physical and chemical principles, understanding of modern depositional environments, and petrographic microscopy.

Geo 5652w. SEDIMENTARY PETROLOGY AND PROCESSES. (5 cr; prereq 3402, 5651 or #; offered alt yrs) Kleinspehn, Paola
Analysis of hand-specimen scale and microscopic features of carbonate and clastic sedimentary rocks and associated chemical, biological, and physical processes. Topics include primary physical structures, petrographic microscopy, diagenesis, and new analytical techniques in sandstone petrology.

Geo 5653. STRATIGRAPHY AND BASIN ANALYSIS. (4 cr [6 cr with lab]; prereq 5651 or #; offered alt yrs) Kleinspehn
Modern techniques and principles of stratigraphic analysis of sedimentary basins in various tectonic settings. Topics include seismic stratigraphy, correlation techniques, paleocurrent analysis, computer basin modeling, and geochronology of sedimentary basins.

Geo 5654. MARINE AND LACUSTRINE SEDIMENTARY ENVIRONMENTS. (4 cr; prereq 5651 or #; offered alt yrs) Kleinspehn
Facies analysis of modern and ancient depositional systems including deltas, fan deltas, barrier islands, beaches, storms, and turbidity currents in lakes and marine settings. Interpretations of marine tidal systems, carbonate platforms, reefs, continental shelves and abyssal-plain processes.

Geo 5655. CONTINENTAL SEDIMENTARY ENVIRONMENTS. (4 cr; prereq 5651 or #; offered alt yrs) Kleinspehn
Principles of facies analysis of modern and ancient non-marine depositional systems.

Geo 5656. DEPOSITIONAL MECHANICS. (3-4 cr; prereq 5651, Math 3261 or #; offered alt yrs) Paola
Elementary mechanics of sediment transport applied to quantitative interpretation of sedimentary rocks.

Geo 5701. SCIENTIFIC VISUALIZATION. (4 cr; prereq CSci 3101, CSci 3102 or CSci 3113 or #)
Practical application to evaluation of data from diverse fields, including geology, geophysics, engineering, and medicine.

Geo 5980. SEMINAR: CURRENT TOPICS IN GEOLOGY AND GEOPHYSICS. (1-6 cr; prereq #)

Geo 5990. SENIOR THESIS. (2 cr per qtr [max 6 cr]; prereq sr Geo or Geophys major, #)
Non-structured research course enabling senior-level majors to do independent research with faculty supervision. Selection of suitable problems according to individual interests and by consultation with faculty committee. Thesis and oral defense.

For Graduate Students or for Seniors with Special Permission

(For descriptions, see *Graduate School Bulletin*)

General Geology

Geo 8097. SEMINAR: CURRENT TOPICS IN GEOLOGY AND GEOPHYSICS

Geo 8098. SEMINAR: CURRENT TOPICS IN GEOLOGY AND GEOPHYSICS

Geo 8099. RESEARCH IN GEOLOGY AND GEOPHYSICS

Geo 8202. ADVANCED STRUCTURAL GEOLOGY

Geo 8203. GEOTECTONICS

Geo 8262. QUATERNARY PALEOECOLOGY AND CLIMATE

Geo 8315. STABLE ISOTOPE GEOCHEMISTRY

Geo 8453. PHASE EQUILIBRIA IN MINERAL SYSTEMS

Geo 8454. IGNEOUS PETROLOGY

Geo 8455. METAMORPHIC PETROLOGY

Geo 8602. ADVANCED LIMNOLOGY

Geo 8612. ANALYTICAL GEOHYDROLOGY

Geo 8617. TRANSPORT PHENOMENA IN NATURAL POROUS MEDIA

Geo 8618. FINITE ELEMENT METHODS IN SUBSURFACE FLOW AND TRANSPORT PROBLEMS

Geo 8620. GEOFLUIDS SEMINAR: FLUID FLOW AND GEOLOGIC PROCESSES WITHIN THE EARTH'S CRUST

Geo 8621. TRACERS IN HYDROGEOLOGY

Geophysics

Geo 8522. TIME-SERIES ANALYSIS OF GEOLOGICAL PHENOMENA

Geo 8543. PRINCIPLES OF ROCK MAGNETISM

Geo 8571. ADVANCED GEODYNAMICS

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. The introductory courses 1711-2-3, 3711-2-3, 1811-2-3, and 3811-2-3 satisfy the Group C liberal education requirement, The Individual and Society (perspectives of history).

The following courses may be used to fulfill liberal education requirements.

HSci 1711, 1712, 1713. TECHNOLOGY AND WESTERN CIVILIZATION. (4 cr per qtr, §3711, §3712, §3713) Layton
History and sociocultural relations of Western technology. *1711:* 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.

HSci 1811, 1812, 1813. INTRODUCTION TO HISTORY OF SCIENCE. (4 cr per qtr, §3811, §3812, §3813) Shapiro
1811. Ancient: Babylonian and Egyptian science; Greek natural philosophy, mathematics, astronomy, and biology; the Aristotelian world; decline and transmission of Greek science. *1812. The Scientific Revolution:* 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. Modern Science:* 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.

HSci 3201, 3202. HISTORY OF BIOLOGY. (4 cr per qtr, §5201, §5202) Beatty
Scientific, philosophical, and social factors in the development of biology; changing styles of biological reasoning, and changing relationships between the biological and physical sciences. *3201:* Biology from antiquity through the early modern period. *3202:* Biology in the 19th and 20th centuries.

HSci 3321. HISTORY OF COMPUTING. (4 cr, §5321) Norberg
History of computing developments in the last century with equal attention to factors affecting the evolution of hardware and software, the growth of the industry and its relation to other business areas, and the changing relationships resulting from new data gathering and analysis techniques.

HSci 3331. TECHNOLOGY AND AMERICAN CULTURE. (4 cr, §5331) Layton, Norberg
Historical survey of the development of American technology in its cultural and intellectual context from the colonial period to the present. Includes transfer of technology to America; establishment of an infrastructure promoting economic growth; relationships among government, corporate, and academic influences; and the social response to technological developments.

HSci 3332. SCIENCE AND AMERICAN CULTURE. (4 cr, §5332) Kolhstedt, Norberg
Historical survey of the development of American science, including the transfer of science to America; development of indigenous traditions for the pursuit of science; establishment of an infrastructure for education and research; response of the public to scientific development; and the relationships among government, corporate, and academic scientists.

HSci 3401. ENGINEERING ETHICS IN HISTORICAL PERSPECTIVE. (4 cr, §5401) Layton, Seidel
Historical survey of engineering ethics in the United States. Successful and unsuccessful strategies for dealing with ethical issues compared using case studies. Emphasis on recent cases such as the Challenger and DC-10 disasters, seen in historical perspective.

HSci 3711, 3712, 3713. TECHNOLOGY AND WESTERN CIVILIZATION. (4 cr per qtr, §1711, §1712, §1713)
See HSci 1711, 1712, 1713.

HSci 3811, 3812, 3813. INTRODUCTION TO HISTORY OF SCIENCE. (4 cr per qtr, §1811, §1812, §1813)
See HSci 1811, 1812, 1813.

HSci 3825. THE NUCLEAR AGE. (4 cr; prereq 5825) Stuewer
Origin, development, and social impact of nuclear physics from the beginning of the 20th century through the post-World War II era. Experimental discoveries; theoretical models of the nucleus; refugees from Nazism; construction and use of the atomic bomb; Oppenheimer and McCarthyism.

HSci 5011. THEORIES OF COLOR: NEWTON TO HELMHOLTZ. (4 cr) Shapiro
Physical and physiological investigations of color from the 17th to the mid-19th centuries, focusing on fundamental contributions of Newton, Young, Maxwell, and Helmholtz.

HSci 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 mathematics and experimental and natural science in Greece; Ptolemaic astronomy.

HSci 5113. NATURAL PHILOSOPHY IN THE SCIENTIFIC REVOLUTION. (4 cr) Shapiro
Emergence of modern science in 17th century. Development of scientific method (nature of scientific explanation, experiment, quantitative approach) and new conceptual basis for physical world (space, matter, force). Bacon, Galileo, Decartes, Boyle, and Newton, among others.

HSci 5201, 5202. HISTORY OF BIOLOGY. (4 cr per qtr, §3201, §3202)
See HSci 3201, 3202.

HSci 5242. THE DARWINIAN REVOLUTION. (4 cr; prereq Biol 1009 or 1101 or #) Beatty
Pre-Darwinian conceptions of nature; development and reception of Darwin's theory of evolution by natural selection; also the broader context of the Darwinian Revolution, including religious thought, political theory, and views about proper scientific methodology.

HSci 5244. HISTORY OF ECOLOGY AND ENVIRONMENTALISM. (4 cr)
Historical development and interaction of ecology as profession and political stance; conservation, Dust Bowl era, population control, DDT controversy, international environmental issues.

HSci 5321. HISTORY OF COMPUTING. (4 cr) Norberg
See HSci 3321.

HSci 5331. TECHNOLOGY AND AMERICAN CULTURE. (4 cr, §3331) Norberg
See HSci 3331.

HSci 5332. SCIENCE AND AMERICAN CULTURE. (4 cr, §3332) Kohlstedt
See HSci 3332.

HSci 5401. ENGINEERING ETHICS IN HISTORICAL PERSPECTIVE. (4 cr, §3401)
See HSci 3401.

HSci 5511. HISTORY OF SCIENTIFIC METHODOLOGY. (4 cr) Beatty
Changing views of the aims and methods of science as seen through the eyes of philosopher-scientists of the past; how notions of "explanation," "hypothesis," "evidence" have changed through time.

HSci 5681. ENGINEERING IN HISTORY. (4 cr) Layton
Civil and mechanical engineering since the Industrial Revolution; complementary roles played by structures and machines in the history of technology. Interaction of structure with aesthetics and machines with science.

HSci 5825. THE NUCLEAR AGE. (4 cr, §3825) Stuewer
See HSci 3825.

HSci 5924. HISTORY OF 19TH-CENTURY PHYSICS. (4 cr, §Phys 5924; prereq general phys or #) Stuewer
Experimental and theoretical discoveries in 19th-century physics (wave theory of light, atomic theory, heat, thermodynamics and statistical mechanics, electromagnetism and field theory) set within the context of concurrent educational, institutional, and political developments in Europe and the United States.

HSci 5925. HISTORY OF 20TH-CENTURY PHYSICS. (4 cr, §Phys 5925; prereq general phys or #) Stuewer
Experimental and theoretical discoveries in 20th-century physics (birth of modern physics, special theory of relativity, old and new quantum theories) set within the context of concurrent educational, institutional, and political developments in Europe and the United States.

HSci 5935. HISTORY OF NUCLEAR PHYSICS. (4 cr; prereq general phys or #) Stuewer
Experimental and theoretical developments in nuclear physics to World War II in their institutional, social, and political contexts. Life and work of Becquerel, Curie, Rutherford, Chadwick, Gamow, Lawrence, Fermi, Bohr, Hahn, Meitner, others.

HSci 5970. DIRECTED STUDIES. (1-15 cr per qtr; prereq #)
Guided individual reading or study.

HSci 5990. DIRECTED RESEARCH. (1-15 cr per qtr; prereq #)

For Graduate Students Only

(For description, see *Graduate School Bulletin*)

HSci 8111. HISTORIOGRAPHY OF HISTORY OF SCIENCE AND TECHNOLOGY

HSci 8121. FOUNDATIONS FOR RESEARCH IN ANCIENT SCIENCE

HSci 8122. FOUNDATIONS FOR RESEARCH IN THE SCIENTIFIC REVOLUTION

HSci 8900. SEMINAR: HISTORY OF EARLY PHYSICAL SCIENCES

HSci 8910. SEMINAR: HISTORY OF MODERN PHYSICAL SCIENCES

HSci 8920. SEMINAR: HISTORY OF BIOLOGICAL SCIENCES

HSci 8930. SEMINAR: HISTORY OF TECHNOLOGY

HSci 8940. SEMINAR: HISTORY OF SCIENCE AND TECHNOLOGY IN AMERICA

HSci 8941. WOMEN IN SCIENCE: HISTORICAL PERSPECTIVES

HSci 8950. SCIENCE AND TECHNOLOGY IN CULTURAL SETTINGS

Industrial Engineering/ Operations Research (IEOR)

Many of the courses listed below have honors sections available. Contact the Student Advising and Information Office, 121 Mechanical Engineering, for more information.

IEOR 3000. INTRODUCTION TO INDUSTRIAL ENGINEERING ANALYSIS. (4 cr; prereq IT student, Math 1252; 3 lect, 1 rec hrs per wk)
Elements of manufacturing and production systems, types of industrial problems solved by the industrial engineer, problem-solving methodology for IE problems, linear programming, artificial intelligence techniques, methods engineering for process improvement, critical path method and PERT, fundamentals of engineering economy, cost estimation, value engineering, concurrent engineering, design for manufacture. Applications may include production scheduling, facility layout, quality engineering, manufacturing automation, product design.

IEOR 5010. INTRODUCTION TO WORK ANALYSIS. (4 cr; prereq IT or grad student, 3000; 3 lect, 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.

IEOR 5020. ENGINEERING COST ACCOUNTING, ANALYSIS AND CONTROL. (4-5 cr; prereq IT or grad student; 3000, ME 3900 recommended; 3 lect, 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.

IEOR 5030. QUALITY ENGINEERING. (4 cr; prereq IT or grad student, Math 1261, ME 3900; 3000 recommended; 3 lect, 1 rec hrs per wk)
Definitions of quality, quality strategy, economics of quality, quality improvement teams, improvement methodologies, the 7 QC tools, control charts, rational sampling, process capability analysis, quality in product design, quality function deployment, total quality management, Deming management methods.

IEOR 5040. INTRODUCTION TO OPERATIONS RESEARCH. (4 cr; prereq IT or grad student, Math 1261; IEOR 3000 recommended; 3 lect, 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.

IEOR 5050. ENGINEERING ECONOMIC ANALYSIS. (4 cr; prereq IT or grad student, 3000 or #; 3 lect, 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, break-even, replacement and investment analysis.

IEOR 5070. INTRODUCTION TO HUMAN FACTORS ENGINEERING. (4 cr; prereq IT student, grad or public health major, #; 3 lect, 1 rec-lab hrs per wk)
Analysis and design of operations, machines, equipment, work stations, and work environments relative to the capabilities, limitations, and needs of the human operator. Topics include human-machine systems, displays, controls, human-machine interface layout, workstation design, anthropometry, work physiology and biomechanics, illumination, noise, toxicology, and climate.

IEOR 5071. HUMAN FACTORS IN SYSTEM DESIGN. (4 cr; prereq 5010 or 5070; 1 lect/rec, 3 hrs scheduled field work per wk)
Application of the theory and principles from IEOR 5070 and 5010 to the analysis and design of real industrial work settings in local industry.

IEOR 5180, 5181. APPLIED INDUSTRIAL ENGINEERING. (3-5 cr [1- or 2-cr term paper option]; prereq background in all basic industrial engineering areas [3000, 5010, 5020, 5030, 5040])
Industrial engineering surveys and programs, case problems, studies in local plants.

IEOR 5221. FACILITIES PLANNING. (4 cr; prereq IT or grad student, 5010, 5020, 5040; 3 lect, 1 rec hrs per wk)
Facilities planning process, relationship to product design, process planning and market requirements, facility location, financial analysis of facility plans, systematic layout planning, computerized layout planning, mathematical modeling, material handling, warehousing.

IEOR 5254. DESIGN MORPHOLOGY WITH APPLICATIONS. (4 cr; prereq upper div ME, completion of sequences ME 3201-3203-3205 or ME 3303 or ME 5342 or #; 1 lect, 7 lab hrs per wk)
Detailed study of design problem formulation and structure of the open-ended solution process based on design morphology. Case studies and student projects as instructional vehicles.

IEOR 5255. ENGINEERING DESIGN PROJECT. (4 cr, [may be repeated for cr]; prereq upper div ME, 5254; 1 lect, 7 lab hrs per wk)
Participation in solving systems design problems that have developed criteria, order-of-magnitude evaluation of alternatives, generation of preliminary design.

IEOR 5311. MANAGEMENT FOR ENGINEERS. (4-5 cr [1- or 2-cr term paper option]; prereq IT or grad student, 3000; 3 lect hrs per wk)
Historical development of management concepts; organizational systems and authority relationships; planning, communication, and management responsibility.

IEOR 5321. INDUSTRIAL SAFETY. (4 cr; prereq IT or grad student, 3000; 4 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.

IEOR 5351. ANALYSIS OF PRODUCTION PROCESSES. (4 cr; prereq IT or grad student, 5020; background in all basic industrial engineering areas [3000, 5010, 5030, 5040] recommended; 4 lect hrs per wk)
Problems in production engineering and production management. Analysis of production problems from selected industries. Development of ability to recognize and diagnose industrial problems.

IEOR 5361. INVENTORY AND PRODUCTION CONTROL. (4 cr; prereq IT or grad student, 3000, 5040, ME 3900; 3 lect, 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.

IEOR 5441. OPERATIONS RESEARCH II. (4 cr; prereq IT or grad student, 5040; 3 lect, 1 rec hrs per wk)
Graph theory, network flow problems, heuristic search, integer and dynamic programming. Industrial applications may include product design, manufacturing planning, facility layout, scheduling, vehicle routing.

IEOR 5442. OPERATIONS RESEARCH III. (4 cr; prereq IT or grad student, 5441; 3 lect, 1 rec hrs per wk)
Optimization in probability models, Markov chains, queuing theory, and simulation.

IEOR 5445. TOPICS IN MANAGEMENT SCIENCE. (3-5 cr [1- or 2-cr term paper option]; prereq IT or grad student; background in all areas of industrial engineering [5010, 5020, 5030, 5040] recommended; 3 lect hrs per wk)
Specialized topics in management science. Analytical tools for decision making and management of the production function. Emphasis on topics appearing in the current literature. Topics vary quarterly.

IEOR 5446. DISCRETE EVENT SIMULATION: INTRODUCTION AND APPLICATIONS. (4 cr; prereq Math 1231, ME 3900, IT grad; 3 lect, 1 rec hrs per wk)
Develop, run, and interpret discrete event simulation models with an emphasis on manufacturing systems. Gain experience with an entity-attribute PC-based simulation language with graphics capability. Statistics issues raised via experimentation. Industry-based course project.

IEOR 5480. HUMAN-MACHINE SYSTEM. (4 cr; prereq 5070 or #, IT or grad student; 3 lect, 1 rec hrs per wk)
Applications of mathematical methods for development of quantitative descriptions and models of human performance with relevance to engineering design. Emphasis on information processing, control, and decision making.

IEOR 5550. DESIGN AND ANALYSIS OF EXPERIMENTS I. (4 cr; prereq IT or grad student, ME 3900; 3 lect, 1 rec hrs per wk)
Theory of variation, scientific method, independent and paired t-tests, analysis of variance, diagnostic checks, model building, gull and fractional factorial designs, Taguchi designs, response surface methodology.

IEOR 5551. DESIGN AND ANALYSIS OF EXPERIMENTS II. (4 cr; prereq IT or grad student, 5550, ME 3900; 3 lect, 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.

IEOR 5703. ENGINEERING PROJECT MANAGEMENT. (4 cr, §CE 5703; prereq IT sr or grad or equiv)
Broad practical understanding of project management, including planning, scheduling, budgeting, staffing, and task and cost control; how to communicate with, motivate, and manage team members.

IEOR 5990. TOPICS IN INDUSTRIAL ENGINEERING. (4 cr; prereq IT student or grad; 5010, 5020, 5030, 5040 recommended [may be repeated for cr]; 4 lect hrs per wk)
Specialized topics within various areas of industrial engineering. Emphasis on topics of current interest. Topics vary quarterly.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

IEOR 8110-8111-8112. ADVANCED INDUSTRIAL ENGINEERING

IEOR 8310-8311-8312. PRODUCTION ENGINEERING PROBLEMS

IEOR 8410-8411-8412. INDUSTRIAL ENGINEERING RESEARCH

IEOR 8420. LINEAR PROGRAMMING

IEOR 8430. NONLINEAR PROGRAMMING

IEOR 8440. DYNAMIC PROGRAMMING

IEOR 8450. QUEUING THEORY

IEOR 8460. STOCHASTIC PROGRAMMING

IEOR 8470. ADVANCED INVENTORY AND PRODUCTION CONTROL

IEOR 8480. HUMAN-MACHINE SYSTEMS

IEOR 8773-8774-8775. GRADUATE SEMINAR

Special Interest Courses for IT Students (IofT)

See page 48.

Materials Science and Engineering (MatS)

MatS 3400. INTRODUCTION TO MECHANICAL PROPERTIES. (4 cr; prereq 2nd-yr IT student; 3 lect, 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 lab/recitation with emphasis on engineering alloys and heat treatment.

MatS 3600H. INTRODUCTION TO MATERIALS SCIENCE, HONORS. (4 cr; prereq selection for IT honors program or consent of IT Honors Office; 3 lect, 1 rec hrs per wk)
Introduction to the properties of solids. Chemical bonding, crystal structures, defects, structure-property relationships, phase diagrams; properties of metals, ceramics, semiconductors, including transport properties and microelectronic devices.

MatS 5011. INTRODUCTION TO THE SCIENCE OF MATERIALS. (4 cr; prereq upper div ChEn or MatS major or #; 3 hrs lect, 2 rec hrs per wk)
General introduction to materials. Metals, polymers, ceramics, glasses, composites, electrical and magnetic materials.

MatS 5012. INTRODUCTION TO DISLOCATIONS AND PHYSICAL METALLURGY. (4 cr; prereq upper div IT, 3400, 5011, AEM 3016 or #; 3 lect, 2 rec hrs per wk)
Basis of work hardening, solid solution strengthening, precipitation hardening, and heat treatment of alloys.

MatS 5013. INTRODUCTION TO ELECTRICAL AND MAGNETIC PROPERTIES OF MATERIALS. (4 cr; prereq upper div IT, 5011 or #; 3 lect, 2 rec hrs per wk)
Introduction to quantum mechanics and semi-quantitative theories on electrical and magnetic properties of solids.

MatS 5101. THERMODYNAMICS OF SOLIDS. (4 cr; prereq Chem 5534 or #; 3 lect, 1 rec hrs per wk)
Fundamental concepts, 1st and 2nd laws, free energy, equilibrium constant, fugacity and activity relationships, solution models, order-disorder.

MatS 5102. DIFFUSION AND SOLID STATE KINETICS. (4 cr; prereq upper div IT, 5101, ChEn 5001 or #; 3 lect, 1 rec hrs per wk)
Kinetics: concepts of reaction rate control by various processes, using gas-solid reactions as an example. Diffusion: interstitial and substitutional diffusion, steady-state and transient systems.

MatS 5112. CERAMICS. (4 cr; prereq upper div IT, 5011, 5101, 5102 or #; 3 lect, 1 rec hrs per wk)
General introduction to ceramics, including glasses. Crystalline and non-crystalline structures, phase relations, ternary phase diagrams; mechanical, thermal, electrical, magnetic, and optical properties of ceramics.

MatS 5200. OPTICAL AND ELECTRON MICROSCOPY OF SOLIDS. (4 cr; prereq upper div IT, 3400 or #; 2 lect, 3 lab hrs per wk)
Practical experience in materials and techniques of evaluation. Investigation of microstructure using optical metallography. Use of transmission electron microscopy, scanning electron microscopy, and elemental microanalysis for metallurgical material systems.

MatS 5202. X-RAY STRUCTURAL ANALYSIS. (4 cr; prereq upper div IT, 5011 or #; 1 lect, 5 lab hrs per wk)
Geometry of crystals; properties and diffraction of X-rays; single crystal Laue methods and powder techniques; crystal structure determination; structure of polycrystals; single crystal orientation; crystal texture; precision lattice parameter measurements, chemical analysis; stress measurements, radiography.

MatS 5304. FAILURE ANALYSIS. (4 cr; prereq 5012, AEM 3016 or #; 2 lect, 4 lab hrs per wk)
Selected materials science and engineering topics such as embrittlement, wear, corrosion, integrated circuit breakdown, vibration, and fatigue. Analysis of failure using metallographic, electron microscopy, and microanalytical techniques.

MatS 5411. MATERIALS DESIGN. (4 cr; prereq sr MatS major, 5012, 5013, 5101, 5200; 3 lect, 1 rec hrs per wk)
Mechanical and thermal processing with applications to forging, extrusion, rolling; advanced topics on heat treatment of steel, titanium, and aluminum alloys, and materials for micro-electronic applications. Materials selection bases on cost and design function.

MatS 5450. CORROSION AND ELECTROCHEMISTRY OF CORROSION. (4 cr; prereq upper div IT, 5101 or #; 3 lect, 2 hrs lab per wk)
Electrochemical thermodynamics, Butler-Volmer equation, electrochemical kinetics, theory of corrosion, passivation, inhibition, forms of corrosion, environmental degradation of mechanical properties, cathodic and anodic protection.

MatS 5455. ELECTROCHEMICAL ENGINEERING. (4 cr, §ChEn 5455; prereq upper div IT or grad, 5101 or ChEn 5201 or #; 4 lect hrs per wk)
Fundamentals of electrochemical engineering. Electrokinetics, thermodynamics of cells, practical and advance cells (batteries), fuel cells, electrosynthesis, and modern sensors.

MatS 5460. OXIDATION OF METALS. (4 cr; prereq upper div IT, 5102 or #; 3 lect, 1 rec hrs per wk)
Theory of high temperature oxidation of metals and alloys; oxidation in complex environments; practical applications and design criteria.

MatS 5470. CORROSION AND ELECTROCHEMISTRY ON HOMOGENEOUS AND HETEROGENEOUS SURFACES. (4 cr; prereq 5450 or 5460 or #; 3 lect, 1 rec hr per wk)
Transport and kinetic phenomena in corrosion processes. Wagner-Traud coupling of oxidation and reduction reactions on homogeneous and heterogeneous surfaces. Principles of current, potential, and concentration distribution modeling in general and localized corrosion.

MatS 5481, 5482, 5483. SPECIAL PROBLEMS IN PHYSICAL METALLURGY AND MATERIALS SCIENCE. (Cr and hrs ar; prereq sr standing)
Library or lab studies of scientific or engineering problems in physical metallurgy and materials science.

MatS 5500. SENIOR DESIGN PROJECT. (4 cr [2 cr in each of two qtrs]; prereq sr MatS major; individual or team project, meetings with assigned adviser)
Allows students to integrate total coursework and lab experience through independent study. Subject area contracted with faculty adviser of student's choice. Term paper and oral presentation required.

MatS 5610. POLYMER CHEMISTRY. (3 cr; prereq upper div IT, Chem 3301 or Chem 3331 or #; 3 lect hrs per wk)
Polymer synthesis characterization. Polymerization types: free radical, condensation, ionic, coordination polymerization kinetics and reactors; molecular weight distribution and its characteristics; network formation; swelling.

MatS 5613. POLYMER LABORATORY. (2 cr; one 4-hr lab per wk)
Students synthesize polymers and characterize their molecular structure and properties. Experiments include anionic polymerization, free radical copolymerization, copolymer ration by IR, molecular size by SEC, crosslinking polymerization, solubility, swelling, crystallization kinetics, thermal transitions by DSC, viscoelasticity, rubber elasticity, tensile properties.

MatS 5620. PROCESSING OF POLYMERS AND THEIR COMPOSITES. (4 cr; prereq heat transfer and fluid mechanics or #; 3 lect hrs per wk, 3-hr lab every other 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, forming, and molding. Thermoset operations—fiber and particulate reinforced composites.

MatS 5630. POLYMER PHYSICAL PROPERTIES. (3 cr; prereq 3400 or 5011 or 5610 or Chem 5610 or #; 3 lect hrs per wk)
Polymer structure-property relations: characterization of structure and morphology of the crystalline and amorphous state. Crystallization kinetics, vitrification and the glass transition, diffusion, viscoelasticity, rubber elasticity, mechanical properties, failure, permeability, optical and electrical properties, polymer composites, effect of processing on properties. Selecting and designing polymers for end use applications.

MatS 5820. THIN FILMS AND INTERFACES OF MICROELECTRONIC MATERIALS. (3 cr; prereq 5013 or #; 3 lect hrs per wk)
Oxidation of Si; formation of interfaces, silicides, and multilayers; interface growth and morphology; thermodynamic and kinetic parameters of evolving interfaces; distribution of reaction products; fabrication of diffusion barriers; epitaxial overlayers; electrical and analytical techniques for characterization.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

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

MatS 8112. SOLID-STATE REACTIONS

MatS 8210. STRUCTURE-PROPERTY RELATIONSHIPS: MECHANICAL AND MICORELECTRONIC

MatS 8213, 8214. ELECTRONIC PROPERTIES OF MATERIALS

MatS 8311. THEORIES OF MECHANICAL BEHAVIOR OF SOLIDS

MatS 8320. HIGH-TEMPERATURE PROPERTIES OF MATERIALS

MatS 8401. TRANSFORMATIONS IN ALLOYS AND ORIGINS OF MICROSTRUCTURE

MatS 8460. OXIDATION OF METALS

MatS 8470, 8471, 8472. SEMINAR: MATERIALS SCIENCE AND ENGINEERING

MatS 8480, 8481, 8482. SELECTED TOPICS IN MATERIALS SCIENCE AND ENGINEERING

MatS 8520. ELECTRON DIFFRACTION AND ELECTRON MICROSCOPY

MatS 8521. TOPICS IN ELECTRON MICROSCOPY

MatS 8522. ADVANCED X-RAY DIFFRACTION OF METALS

Mathematics (Math)

Note: The Math Department expects each student to have and use a scientific calculator. More powerful calculators are not usually required but are always permitted. Math courses listed as prerequisites must have been passed with a grade of C or better. Students who ignore prerequisites may be asked to withdraw from the course.

Math 1001. EXCURSIONS IN MATHEMATICS. (See *College of Liberal Arts Bulletin*)

Math 1008. TRIGONOMETRY. (See *College of Liberal Arts Bulletin*)

Math 1031. COLLEGE ALGEBRA AND PROBABILITY. (*See College of Liberal Arts Bulletin*)

Math 1051. PRECALCULUS I. (4 cr; §1008, §1031, §1111, §1151, §1201; prereq 3 yrs high school mathematics, placement exam or GC 0631 with a grade of C or better)
Algebra, analytic geometry, and trigonometry beyond the usual coverage found in a three-year high school mathematics program. First of two courses (see 1151). Prepares students for the full calculus sequence. Not an acceptable prerequisite for 1131.

Math 1131. FINITE MATHEMATICS. (See *College of Liberal Arts Bulletin*)

Math 1142. SHORT CALCULUS. (See *College of Liberal Arts Bulletin*)

Math 1151. PRECALCULUS II. (4 cr, §1008, §1111, §1201; prereq 3½ yrs high school mathematics, placement exam or 1051 with a grade of C or better)
Second of two courses (see 1051) in algebra, analytic geometry, and trigonometry. Prepares students for the full calculus sequence. Not an acceptable prerequisite for 1131.

Math 1251-1252. ONE-VARIABLE DIFFERENTIAL AND INTEGRAL CALCULUS I-II. (4 cr each, §1211-1221, §1411H-1421H, §1451H-1452H; prereq 4 yrs high school mathematics including trigonometry or grade of C or better in 1151 or equiv; grade of C or better in 1251 required for 1252)
Calculus of functions of one variable and related geometry and applications.

Math 1261.CALCULUS III. (4 cr, §1353; prereq 1252 or 1352 or equiv)
Further topics in calculus: parametic curves, polar coordinates, power series, Taylor polynomial. Linear algebraic equations, Gaussian elimination, determinants. Applications.

Math 1268. SHORT COURSE: INTRODUCTION TO LINEAR ALGEBRA. (2 cr, §1261, §3221, §3142; prereq differential equations course)
Matrices, Gaussian elimination, determinants. Course offers in isolation the linear algebra of Math 1261. Designed for transfer students who have already had a course in differential equations. Meets the first four weeks of the quarter concurrent with Math 3221.

Math 1351-1352-1353 CALCULUS: CONCEPTS, EXPLORATIONS, AND APPLICATIONS. (4 cr each, §1251 for 1351, §1252 for 1352, §1261 for 1353; prereq background in precalculus and geometry and visualization of functions and graphs, #; familiarity with graphing calculator recommended; grade of C or better required to continue sequence)
Reformed approach to calculus: cooperative learning/small groups, labs, projects. Technology and applications emphasized with interdisciplinary modules. *1351:* Functions, differentiation. *1352:* Antiderivatives, integration. *1353:* Differential equations, parametric curves, series, basic linear algebra.

Math 1551H-1552H. HONORS: ONE-VARIABLE DIFFERENTIAL AND INTEGRAL CALCULUS I-II. (4 cr each, §1211-1221, §1251-1252, §1411-1142H; prereq consent of IT Honors Office, grade of C or better in 1551H required for 1552H)
Honors-level treatment of calculus of functions of one variable and related geometry and applications, including infinite sequences and series.

Math 1553H-3551H-3552H. HONORS: LINEAR AND NONLINEAR ANALYSIS I-II-III. (4 cr each; some parts of this course may not be taken for credit by students with previous 3xxx Math courses—adviser approval required; prereq 1251-1252 or 1551H-1552H or equiv; grade of C or better required to continue in sequence)
Four major topics distributed approximately as follows. *1553H:* Vector geometry and linear algebra. *3551H:* Ordinary differential equations. *3551H-3552H:* Multivariable differential calculus. *3552H:* Multivariable integral calculus. Taking courses in consecutive quarters recommended.

Math 1711H-1721H-1731H. SECONDARY STUDENTS HONORS CALCULUS I-II-III. (4 cr per qtr; prereq #, Δ)
Accelerated honors sequence for selected mathematically talented high school students. Essentially the same as 1551H-1552H, plus applications to science and engineering. Emphasis on theory and computations.

Math 3001. ACTUARIAL SCIENCE SEMINAR. (1 cr; prereq soph; S-N only)
Actuarial science and related fields as careers. Lectures by practicing actuaries and others. Sample employment interviews at insurance or consulting companies.

Math 3007H-3008H. THE WORLD OF MATHEMATICS. (1 cr per qtr; prereq instructor permission and grade of at least B in Math 3511H; grade of B or better to continue in sequence)
Mathematics, a subject of creative thought and the theoretical base of the scientific enterprise. Topics in pure and applied mathematics and history. Lectures by mathematicians and users of mathematics. Mathematics as a career. A preview of upper division math courses.

Math 3066. ELEMENTARY DIFFERENTIAL EQUATIONS. (4 cr, §3213, §3221, §3261, §3521; this course will not be taught; for info only)
Elementary techniques of problem solving. First- and second-order equations, linear equations of higher order.

Math 3105-3106-3107 (formerly 1105-1106). TOPICS IN ELEMENTARY MATHEMATICS. (See *College of Liberal Arts Bulletin*)

Math 3142. LINEAR ALGEBRA. (5 cr, §1241, §1261; prereq 1221 or 1252)
Practical course in linear algebra, including vector spaces, matrices, determinants, linear algebraic equations and Gaussian elimination, basis and dimension, linear transformation, eigenvalues and eigenvectors, bilinear forms, diagonalization.

Math 3221. INTRODUCTION TO LINEAR ALGEBRA AND DIFFERENTIAL EQUATIONS. (5 cr; §1261, §3066, §3261, §3552H; prereq one yr calculus)
Combines the linear algebra from Math 1261 with the major topics of Math 3261. Designed for transfer students with one year of calculus. Students who have some linear algebra, or who have taken Math 1261 at this University, should take 3261 instead. Algebra part available separately as Math 1268.

Math 3251. MULTIVARIABLE DIFFERENTIAL CALCULUS. (4 cr, §3211, §3311, §3521H, §3552H; prereq 1261 or 1353)
The algebra and geometry of vectors in 3-space. Velocity, acceleration, and curvature. Functions of several variables. Partial derivatives and the chain rule. Applications to max/min problems. Lagrange multipliers.

Math 3252. MULTIVARIABLE INTEGRAL CALCULUS. (4 cr, § for students with both 3311 and 3331, or both 3211 and 3331, §3551H, §3552H; prereq 3251 or ¶3251)
Double and triple integrals; change of variable procedures, with emphasis on polar and spherical coordinates; mass and centroid; integration on curves and surfaces; vector fields and the Theorems of Green, Gauss, and Stokes.

Math 3261. DIFFERENTIAL EQUATIONS WITH LINEAR ALGEBRA. (4 cr, §3221, §3321, §3531H, §3551H; prereq one yr calculus [e.g., 1261 or 1353])
Differential equations, including first-order equations, linear equations with constant coefficients, and linear systems. Companion topics from linear algebra: general vector spaces, independence, spanning sets, basis, dimension, eigenvalues, eigenvectors.

Math 3262. SEQUENCES, SERIES, AND FOUNDATIONS. (4 cr; prereq 1261)
Elements of logic; mathematical induction; the real number system; general, monotone, and recursively defined sequences; convergence; infinite series and convergence; Taylor's series; power series with applications to differential equations; Newton's method.

Math 3511H. HONORS: LINEAR ANALYSIS. (5 cr, §1261; prereq 1731H)
Continuation of Math 1731H, intended for selected mathematically talented high school students. Ideas and computations of linear algebra, including linear independence, linear transformations, matrices, and determinants. Students who complete this course may enter 3551H or any course for which 1261 is the prerequisite.

Math 3551H-3552H. HONORS: LINEAR AND NONLINEAR ANALYSIS II-III.
See Math 1553H.

Math 5056. THE THEORY OF INTEREST. (4 cr; prereq 1252 or equiv)
Time value of money. Accumulation function with compound interest as an important special case. Annuities, sinking funds, bonds, depreciation. Primarily for mathematics and business majors interested in actuarial science.

Math 5057-5058-5059. ACTUARIAL MATHEMATICS I-II-III. (4 cr each; prereq 5056, one qtr 5xxx-level probability or statistics such as 5679 or Stat 5131)
5057: Survival function; actuarial notation; actuarial present values for life insurance and life annuities; net premiums. *5058:* Equivalence principle; reserves; multiple life functions and multiple decrement models; valuation of pensions. *5059:* Further topics at instructor's discretion.

Math 5105-5106-5107. DIVERSITY IN MATHEMATICS. (4 cr, prereq 1031 or equiv or #; §1105, §3105 for 5105, §1106, §3106 for 5106, §3107 for 5107; cr for elem ed grads only)
Mathematical enrichment for elementary school instructors. Number theory (primes and congruences), fractions and decimals, regular and semi-regular polyhedra, map coloring, graph theory, game theory.

Math 5151. ELEMENTARY SET THEORY. (4 cr; prereq 32xx math course or equiv or #)
Basic properties of operations on sets, cardinal numbers, simply ordered sets, well-ordered sets, ordinal numbers, axiom of choice, axiomatics.

Math 5152. ELEMENTARY MATHEMATICAL LOGIC. (4 cr, §5163; prereq 32xx math course or equiv or #)
Grammar and semantics of first and second-order languages; relational structures; a deductive system for first-order logic; completeness theorem; axiomatics of formal theories.

Math 5162-5163-5164. MATHEMATICAL LOGIC. (4 cr per qtr; prereq 1 yr calculus or equiv or Phil 5202 or #)
5162: Theory of computability; notion of algorithm, Turing machines, primitive recursive functions, recursive functions, Kleene Normal Form, Recursion Theorem. *5163:* Provability and truth in formal systems: propositional and predicate logic, models of axiom systems, Goedel Completeness Theorem, nonstandard analysis. *5164:* Goedel Incompleteness Theorem: decidable and undecidable theories, models of arithmetic.

Math 5209. THEORY OF NUMBERS. (4 cr; prereq 32xx math course or equiv or #)
Rigorous introduction to the elementary theory of numbers up to the classical results concerning congruences to a prime modulus (e.g., Fermat's theorem). Usually covers one more advanced topic such as continued fractions, Gaussian integers, or quadratic reciprocity.

Math 5232-5233. COMPUTER-ORIENTED LINEAR ALGEBRA. (4 cr per qtr, §5242-5243, §5247, §5284; prereq 1261, 3261 or 3142 or equiv or #)
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.

Math 5242-5243. LINEAR ALGEBRA WITH APPLICATIONS. (4 cr per qtr, §5232-5233, §5247, §5284; prereq 1261, 3261 or 3142 or equiv or #)
Systems of linear equations, finite dimensional linear spaces, bases, linear transformations, matrices, determinants, eigenvalues, reduction to canonical forms, quadratic and bilinear forms, applications.

Math 5245-5246-5247. INTRODUCTION TO MODERN ALGEBRA I-II-II. (4 cr per qtr, §5282 for 5245, §5283 for 5246, §5284 for 5247; prereq three 32xx math courses or equiv or #)
Basic algebra course; a more concrete level than 5282-5283-5284. Group theory including normal subgroups, homomorphism, automorphism, the theory of Lagrange and Cayley. Ring theory including ideals, integral domains, Euclidean rings, polynomial rings, and fields. Linear algebra including an abstract approach to vector spaces, and linear transformations and their structure. Taking this course non-sequentially is not recommended.

Math 5282-5283-5284. FUNDAMENTAL STRUCTURES OF ALGEBRA. (4 cr per qtr, §5245; prereq one soph sequence or #; some previous abstract mathematics recommended)
Theory course, primarily for students planning mathematics graduate work. Group theory: normal subgroups, homomorphism, automorphism, the theorems of Lagrange, Cayley, and Sylow. Ring theory: rings, ideals, integral domains, Euclidean rings, polynomial rings, fields. Linear algebra: abstract approach to vector spaces, linear transformations; the theory of canonical forms, including the Jordan and rational.

Math 5331-5332-5333. GEOMETRY I-II-III. (4 cr per qtr, §3161 for 5331, §5083 for 5332; prereq 1261 or equiv)
Advanced Euclidean geometry; axiomatic and analytic hyberbolic geometry; projective geometry; symmetry and geometrical transformations and their connections with linear algebra, group theory, and complex arithmetic; finite geometries; convex geometrical figures.

Math 5337. COMPUTATIONAL METHODS IN ELEMENTARY GEOMETRY. (4 cr; prereq multivariable calculus [e.g., 3251] or #)
Technological tools such as interactive computer graphics programs and videos of computer animations introduced and used to explore mathematical concepts from various branches of geometry.

Math 5341-5342. INTRODUCTION TO TOPOLOGY. (4 cr per qtr; prereq one soph sequence or #; some previous abstract mathematics recommended)
Set theory; axiom of choice, Zorn's lemma. Metric spaces: completeness, compactness, continuity. Basic point set topology: countability and separation axioms, Urysohn's lemma, compactness, connectedness, product spaces.

Math 5343. INTRODUCTION TO ALGEBRAIC TOPOLOGY. (4 cr; prereq 5342)
Classification of two-manifolds, fundamental group, homology theory.

Math 5375-5376-5377. DIFFERENTIAL GEOMETRY. (4 cr per qtr; 5375: prereq 3252 or equiv or #; 5376: prereq 3142 or 3261 or equiv, 5375)
5375: Plane and space curves. Frenet formulas, elementary theory of surfaces. *5376-5377:* Differential forms. Advanced theory of surfaces, integral geometry, Riemannian geometry.

Math 5381-5382-5383. INTRODUCTION TO COMPUTATIONAL ALGEBRAIC GEOMETRY. (4 cr each; prereq multivariable differential calculus [e.g., 1261, 3251])
Geometry of curves and surfaces defined by polynomial equations. Emphasis on concrete computations with polynomials using computer algebra packages, and on the interplay between algebra and geometry. Abstract algebra presented as needed—no algebra prerequisite.

Math 5404. VARIATIONAL PROBLEMS. (4 cr; prereq 3252, 3261 or equiv or #)
Introduction to the calculus of variations and its applications. Topics may include fundamental theory, Euler-Lagrange equations, necessary and sufficient conditions, stability, isoperimetric problems, rudiments of the Mayer-Lagrange-Bolza problems, multiplier rule, direct methods, Rayleigh-Ritz method, eigenvalue problems, multiple integrals.

Math 5428. MATHEMATICAL MODELING. (4 cr; prereq 2 yrs elem calculus)
Methodology and practice in developing and analyzing mathematical models of problems in physical, social, and engineering sciences. Team approach to case studies..

Math 5447-5448-5449. MATHEMATICAL THERMODYNAMICS. (4 cr per qtr; prereq 5607 or 5613 or [5567, 5568] or #; primarily for math majors interested in applications, engineers, scientists)
5447-5448: Introduction to mathematical structures underlying classical thermodynamics. Concepts of heat, hotness, and material systems; rigorous formulation of laws of thermodynamics; general accumulation theorem; absolute temperature; Carnot cycles (and efficiency of heat engines). Applications to quasi-static and irreversible systems, concept of entropy. *5449:* Equilibrium of thermal systems. Gibbsian equilibrium theory and phase rule; applications to mixtures and phase transitions. Thermodynamics of continuous systems. Clausius-Duhem inequality.

Math 5457-5458-5459. METHODS OF APPLIED MATHEMATICS. (4 cr per qtr; prereq 3252, 3261 or equiv)
Modern analytic tools used in applications of mathematics; emphasis on technique. Linear algebra, ordinary and partial differential equations, calculus of variations, Fourier series, complex variables, optimization, numerical methods.

Math 5463-5464-5465. THE MATHEMATICS OF INDUSTRIAL PROBLEMS. (4 cr; prereq 2 yrs calculus incl ¶3262 or equiv, familiarity with FORTRAN or PASCAL or C, #)
Industrial problems such as crystal precipitation, air quality modeling, color film developing, laser semiconductors. Theoretical foundations and computational methods involving ordinary and partial differential equations, calculus of variations, and numerical analysis.

Math 5467. INTRODUCTION TO THE MATHEMATICS OF WAVELETS. (4 cr; prereq 2 yrs calculus or #)
Background theory and experience in wavelets. Inner product spaces, operator theory, and Fourier transforms applied to Gabor transforms, multi-scale analysis, discrete wavelets, and self-similarity. Computing techniques.

Math 5473-5474-5475. ANALYSIS OF NUMERICAL METHODS. (4 cr per qtr; 3252, 3261 or equiv; some computer skills recommended)
Interpolation and approximation by polynomials. Solution of linear and nonlinear systems of equations. Methods of eigenvalue problems. Numerical integration. Numerical solution of ordinary differential equations. Selected topics if time permits.

Math 5477-5478-5479. APPLIED NUMERICAL ANALYSIS OF PARTIAL DIFFERENTIAL EQUATIONS. (4 cr; prereq 5242 or equiv, 5513 or equiv, 5608 or equiv, computer skills or #)
Numerical methods for partial differential equations of linear and nonlinear elasticity, compressible and incompressible fluid flow, multiphase flow, heat transfer, and other selected systems of partial differential equations.

Math 5512-5513. DIFFERENTIAL EQUATIONS WITH APPLICATIONS I-II. (4 cr per qtr; prereq 3261 or equiv or #; 3262 recommended)
<6>*5512:* 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:* 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.

Math 5514. INTEGRAL EQUATIONS. (4 cr; prereq 3261 or 5512 or equiv or #)
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.

Math 5521-5522-5523. INTRODUCTION TO ORDINARY DIFFERENTIAL EQUATIONS. (4 cr per qtr; prereq one soph sequence or #)
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:* Power series solutions, majorant method; regular and irregular singular points; error estimates, perturbation methods.

Math 5531-5532-5533. DYNAMICAL SYSTEMS AND CHAOS. (4 cr; prereq 1261-3251-3252-3261)
Introduction to dynamical systems theory with emphasis on iteration of mappings of line, circle, and plane. Fixed points, periodic points, stability, bifurcations, invariant Cantors sets, rotation number, Smale horseshoe, fractal dimension, Julia sets, Mandelbrot set, nonlinear oscillations, computer experiments.

Math 5553H (formerly 3541H). HONORS: COMPLEX ANALYSIS AND RELATED TOPICS. (4 cr, §3331, §5568; prereq 3531H or 3552H)
Differentiation of complex-valued functions of a complex variable; major theorems on analytic functions; power series, Laurent series, other topics in sequences and series.

Math 5567. FOURIER SERIES AND BOUNDARY VALUE PROBLEMS. (4 cr, §5571; prereq 3261 or equiv or #; 3262 recommended)
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.

Math 5568. ELEMENTARY THEORY OF COMPLEX VARIABLES. (4 cr, §3541H, §5553H, §5572; prereq 3252 or equiv)
Derivative and integral of a function of a complex variable. Cauchy integral theorem and formula, residues. Application to evaluation of integrals, conformal mapping.

Math 5569. OPERATIONAL MATHEMATICS. (4 cr, §5573; prereq 5568)
Laplace transforms, Fourier transforms, inversion theorems; applications to differential equations.

Math 5571-5572-5573. ELEMENTARY PARTIAL DIFFERENTIAL EQUATIONS. (4 cr per qtr, §5568 for 5572-5573; prereq 5613 or ¶5608)
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.

Math 5606-5607-5608. ADVANCED CALCULUS: A RIGOROUS APPROACH. (4 cr per qtr, §5612 for 5606, §5613 for 5607, §5614 for 5608; prereq 3252 or equiv; ¶3262 recommended)
Basic analysis course; a more concrete level than 5612-5613-5614. Foundations of analysis: completeness of the line, limits, convergence, continuity, integration. *5606-5607:* Analysis on the line. *5608:* Analysis in Euclidean space. Other topics at instructor's discretion.

Math 5612-5613-5614. INTRODUCTION TO ANALYSIS. (4 cr per qtr; prereq 3252, ¶3262; primarily for students planning graduate work in mathematics)
Theory of real numbers; elements of point set theory; limits; differentiation; multivariable analysis.

Math 5679. PROBABILITY. (4 cr, §5681, §Stat 5131; prereq 3252 or equiv)
Elementary principles of probability, total and conditional probability, expectation, repeated trials, and topics chosen from the following: Stirling formula, the probability integral, geometrical probability, probability of causes, Bayes theorem, errors of observation, principle of least squares.

Math 5681-5682-5683. INTRODUCTION TO PROBABILITY. (4 cr per qtr, §5679, §Stat 5131 for 5681; prereq 3252; ¶3262 recommended)
Logical development and various applications of probability. Probability spaces, random variables, central limit theorem; Markov chains.

Math 5701. ENUMERATIVE COMBINATORICS. (4 cr; prereq 3251 or equiv; 3xxx linear algebra course recommended)
Basic enumeration. Sets, permutations, distributions, partitions, generating functions (exponential and ordinary), recurrence relations, the method of inclusion-exclusion, and Polya theory.

Math 5702. GRAPH THEORY AND OPTIMIZATION. (4 cr; prereq 3251 or equiv; 3xxx linear algebra recommended)
Basic concepts in graph theory. Connectedness, Hamiltonian and Eulerian paths, trees, coloring, and matchings. Topics in optimization: networks, flows, spanning trees, and graph algorithms. Definitions and examples of designs, Latin squares, and codes.

Math 5703. CONSTRUCTIVE COMBINATORICS. (4 cr; prereq 5701, knowledge of some programming language)
Algorithmic and bijective approaches to permutations, subsets, trees, tableaux, and partitions, ranking and unranking algorithms. Connections with generating functions. The Lagrange inversion formula.

Math 5900. TUTORIAL COURSE IN ADVANCED MATHEMATICS. (Cr ar; prereq #)
Qualified students whose needs are not met by courses offered may make arrangements to study content of other courses.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

Math 8140-8141-8142. APPLIED LOGIC

Math 8166-8167-8168. RECURSION THEORY

Math 8190-8191-8192. TOPICS IN LOGIC

Math 8200-8201-8202. GENERAL ALGEBRA

Math 8203-8204-8205. ALGEBRAIC GEOMETRY

Math 8206-8207-8208. ALGEBRAIC NUMBER THEORY

Math 8209-9210. HOMOLOGICAL ALGEBRA

Math 8211-8212. COMMUTATIVE ALGEBRA

Math 8250-8251-8252. TOPICS IN GROUP THEORY

Math 8263-8264-8265. TOPICS IN ALGEBRAIC GEOMETRY

Math 8266-8267-8268. TOPICS IN NUMBER THEORY

Math 8270-8271-8272. LIE GROUPS AND LIE ALGEBRAS

Math 8290-8291-8292. TOPICS IN ALGEBRA

Math 8300-8301-8302. MANIFOLDS/TOPOLOGY

Math 8306-8307-8308. ALGEBRAIC TOPOLOGY

Math 8330-8331-8332. DIFFERENTIAL TOPOLOGY

Math 8342-8343-8344. TOPOLOGICAL DYNAMICS

Math 8365-8366-8367. RIEMANNIAN GEOMETRY

Math 8370-8371-8372. TOPICS IN GEOMETRY

Math 8380-8381-8382. TOPICS IN ADVANCED DIFFERENTIAL GEOMETRY

Math 8406-8407-8408. ADVANCED METHODS OF APPLIED MATHEMATICS

Math 8430-8431-8432. MATHEMATICAL THEORY OF FLUID DYNAMICS

Math 8445-8446-8447. NUMERICAL ANALYSIS OF ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS

Math 8450-8451-8452. TOPICS IN NUMERICAL ANALYSIS

Math 8460-8461-8462. MATHEMATICAL PROBLEMS IN THEORETICAL PHYSICS

Math 8480-8481-8482. SELECTED TOPICS OF CELESTIAL MECHANICS

Math 8500-8501-8502. THEORY OF ORDINARY DIFFERENTIAL EQUATIONS

Math 8540. TOPICS IN DIFFERENTIAL AND DIFFERENCE EQUATIONS

Math 8550-8551-8552. THEORY OF PARTIAL DIFFERENTIAL EQUATIONS

Math 8560-8561-8562. CALCULUS OF VARIATIONS AND MINIMAL SURFACES

Math 8570-8571-8572. INFINITE DIMENSIONAL DYNAMICAL SYSTEMS

Math 8590-8591-8592. TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS

Math 8600-8601-8602. REAL ANALYSIS

Math 8620-8621-8622. THEORY OF SINGULAR INTEGRALS

Math 8640-8641-8642. TOPICS IN REAL ANALYSIS

Math 8650-8651-8652. THEORY OF PROBABILITY

Math 8653-8654. INTRODUCTION TO STOCHASTIC PROCESSES

Math 8656-8657-8658. MEASURE THEORY AND PROBABILITY

Math 8668-8669-8670. INTRODUCTION TO COMBINATORIAL THEORY

Math 8672, 8673, 8674. TOPICS IN COMBINATIONAL THEORY

Math 8690-8691-8692. TOPICS IN THE THEORY OF PROBABILITY

Math 8700-8701-8702. COMPLEX ANALYSIS

Math 8790-8791-8792. TOPICS IN THE THEORY OF ANALYTIC FUNCTIONS

Math 8800-8801-8802. FUNCTIONAL ANALYSIS

Math 8990-8991-8992. READING AND RESEARCH

Mechanical Engineering (ME)

Many of the courses listed below have honors sections available. Contact the Student Advising and Information Office, 121 Mechanical Engineering (612/625-5842) for more information.

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

ME 1025. ENGINEERING GRAPHICS. (4 cr; prereq IT student, Math 1251 or equiv; 3 lect, 1 rec hrs per wk, open lab hrs)
Engineering representation in pictorial view and multiview; sketching techniques, size description, standard and simplified practices applied to graphical communication. Analysis of systems of projection; correlation of graphical, numerical, and computer solutions of space problems, intersections and development. Methods of computer-aided graphics.

ME 3020. MECHANICAL ENGINEERING COMPUTATION. (4 cr; prereq IT student, Math 3261 or equiv, CSci 3101; 3 lect, 1 lab-rec hrs per wk)
Application of numerical methods and FORTRAN programming to the solution of mechanical engineering problems. Engineering programming style. Methods for solving linear and non-linear engineering equations. Interpolating and displaying engineering data. Simulating mechanical systems. Thermal analysis using finite difference techniques.

ME 3201. MECHANICAL ENGINEERING SYSTEMS ANALYSIS. (4 cr, §AEM 3401; prereq ME or AEM student, AEM 3036; 3 lect, 2 lab hrs per wk)
Determination of response of engineering systems using transfer function representation. Analogies between engineering systems based on transfer function equivalence.

ME 3203. ANALYSIS OF MECHANISM SYSTEMS. (4 cr; prereq upper div ME, 3020, AEM 3036 or equiv; 3 lect, 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.

ME 3205. ENGINEERING SYSTEMS DESIGN. (4 cr; prereq upper div ME, AEM 3016; 3 lect, 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.

ME 3301. THERMODYNAMICS. (4 cr; prereq IT or forest product student, Chem 1014 or Chem 1052 or Phys 1252, Math 3261 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.

ME 3303. APPLIED THERMODYNAMICS. (4 cr, §3305; prereq upper div ME or AEM, 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.

ME 3305. PROPULSION THERMODYNAMICS. (4 cr, §3303; prereq ME or AEM student, 3301, AEM 5200 or equiv; 4 lect hrs per wk)
Principles of thrust production, momentum, energy and mass flow functions; chemical equilibrium, combustion, flame temperature. Thermodynamics of turbojet, turbofan, turboprop, rocket and engine units.

ME 3701-3702. BASIC MEASUREMENTS LABORATORY I-II. (2 cr per qtr; prereq upper div ME, 3301 or ¶3301 for 3701, 3701 for 3702; 1 lect, 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.

ME 3741-3742-3743. INDUSTRIAL ASSIGNMENT. (2 cr per qtr; prereq ME undergrad, regis in co-op program for 3741, 3741 for 3742, 3742 for 3743)
Industrial work assignment in engineering intern program. Evaluation based on student's formal written report covering the quarter's work assignment.

ME 3900. INTRODUCTION TO ENGINEERING STATISTICS. (4 cr; prereq IT student, Math 1261 or equiv; 3 lect, 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.

ME 5190. ADVANCED ENGINEERING PROBLEMS. (2-4 cr; prereq submission of approved dept permission form; open to upper div students)
Special investigations in various fields of mechanical engineering and related areas including an independent study project.

ME 5203. ADVANCED ANALYSIS AND SYNTHESIS OF MECHANISM SYSTEMS. (3-4 cr; prereq IT or grad student, 3203 or equiv; computer programming desirable; 3 lect hrs per wk)
Analytical methods of kinematic, dynamic, and kineto-elasto-dynamic analysis and synthesis of mechanisms. Computerized design for function, path and motion generation based on Burmester theory.

ME 5205. CREATIVITY IN ENGINEERING DESIGN. (3-4 cr [1-cr term paper option]; prereq IT or grad student; 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.

ME 5207. EXPERIMENTAL STRESS ANALYSIS. (4 cr; prereq upper div IT or grad, AEM 3016; 3 lect, 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 using strain.

ME 5209. FRICTION AND LUBRICATION. (3-4 cr [1-cr term paper option]; prereq IT or grad student, AEM 3200 or 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.

ME 5220. COMPUTER-AIDED DESIGN, OPTIMIZATION, AND COMPUTER GRAPHICS. (4 cr; prereq IT or grad student, 1025, 3030, 3203, 3205; 3 lect, 1 rec hrs per wk)
Application of computer-aided engineering to mechanical design. Engineering design projects and case studies using computer-aided design software, design optimization, and computer graphical presentation of results.

ME 5225. FINITE ELEMENTS IN MECHANICAL DESIGN. (4 cr; prereq IT or grad student, 3205, 5342, programming; offered CEE spring qtr)
Introduction to fundamentals of finite element analysis, oriented to mechanical engineering design applications. Extensive examples from industry and student projects involving actual set-up and solution of descriptive problems using industry-accepted analysis codes and interactive graphics for model generation.

ME 5226. FINITE ELEMENT METHODS IN MECHANICAL ENGINEERING I. (4 cr; prereq upper div IT or grad student, 3020, AEM 3016, Math 3261, FORTRAN programming)
Introduction to computational methods, direct stiffness approach, introduction to elasticity and energy methods. Interpolation, development of simple finite elements, assembling, solution methods. Programming considerations and design application.

ME 5227. FINITE ELEMENT METHODS IN MECHANICAL ENGINEERING II. (4 cr; prereq upper div IT or grad student, 5226 or #, programming)
Fundamental concepts of FEM; variational and weighted residual methods; interpolation functions; linear/higher order elements; methodology and formulation for one-end two-dimensional problems in structural mechanics and heat transfer; axisymmetric problems; solution schemes for linear-nonlinear static/steady-state models; computer implementation.

ME 5230. ACOUSTICS AND VIBRATION LABORATORY. (2 cr; prereq upper div ME, 3201, 3701, 3702)
Transducers and signal conditioning for acoustic and vibration measurement; sinusoidal, impulse, and stochastic identification techniques; modal analyzers, comparison of analytical and experimental modal results.

ME 5231. MECHATRONICS LABORATORY. (2 cr; prereq upper div ME, 3201, 3701, 3702)
Computer control of servomechanisms; motor and mechanical drive component types and selection; power electronics; microprocessors and programmable controllers; digital control; position, force, and velocity measurement; performance prediction and testing techniques.

ME 5233. PROGRAMMABLE AUTOMATION. (2 cr; prereq upper div ME, 3702)
Programmable logic controllers, machine tool and robot controllers and factory automation networks. Programming methods for PLCs. Group project to design a controller for a flexibly automated multi-station assembly or fabrication cell.

ME 5244. VIBRATION ENGINEERING. (4 cr; prereq IT or grad student, 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.

ME 5254. DESIGN MORPHOLOGY WITH APPLICATIONS. (4 cr; prereq upper div ME; completion of [3201, 3203, 3205], [3303, 5342] or #; 1 lect, 7 lab hrs 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.

ME 5255. ENGINEERING DESIGN PROJECT. (4 cr [may be repeated for cr]; prereq upper div ME, 5254; 1 lect, 7 lab hrs per wk)
Participation in solution of systems design problems that have developed criteria, order-of-magnitude evaluation of alternatives, and generation of preliminary design.

ME 5260. ENGINEERING MATERIALS AND PROCESSING. (4 cr; prereq upper div ME, 3020, AEM 3016, Chem 1052, MatS 3400, Phys 1253; 3 lect, 1 rec hrs per wk; safety glasses required)
Introduction to materials and processing including physical and metallurgical properties, consolidation, etc. Material processing including machining, welding, and deformation processes.

ME 5262. MATERIAL WORKING AND FABRICATION PROCESSES. (4 cr; prereq IT or grad student, 5260 or equiv; 3 lect, 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.

ME 5264. MATERIAL CONSOLIDATION PROCESSES. (4 cr; prereq IT or grad student, 5260 or equiv; 3 lect, 1 rec hrs per wk)
Theory and practice of material consolidation including casting and powder metal processes. Composite materials techniques.

ME 5265. COMPUTER-ASSISTED PRODUCT REALIZATION. (4 cr, prereq IT or grad student, 5260 or equiv, engineering computer language course; 2 lect, 6 lab hrs per wk)
Integration of computer-based engineering, design, and manufacture to reduce concept-to-product cycle time. Course requires planning and execution of a product and process design to fulfill functional requirements using software tools. Team project to instill appreciation of issues in integration of design and manufacture.

ME 5268. PROPERTIES AND FABRICATION OF PLASTICS. (4 cr; prereq IT or grad student, 5260 or equiv; 3 lect, 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.

ME 5270. MATERIALS—DESIGN REQUIREMENTS. (4 cr; prereq IT or grad student, 5260 or equiv; 3 lect, 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.

ME 5271. ROBOTICS. (3-5 cr [2-cr lab option]; prereq IT or grad student, 5283 or equiv)
Analyzing and designing computer control mechanical systems with multiple degrees of freedom. Robotics, multi-jointed manipulator kinematics, dynamics, control, integration with sensors. Position, velocity, path, force control. Lab projects.

ME 5272. NON-CONTACT SENSING. (3-5 cr [2-cr lab option]; prereq IT or grad student, 5283 or equiv)
Optical and acoustic-based sensing for inspection measurement and closed-loop control. Mathematics of image processing as used in sensors. Inspection, part classification, tracking, ranging. Lab projects.

ME 5275. COMPUTER-CONTROLLED EXPERIMENTATION. (4 cr; prereq IT or grad student, 5283 or equiv; 3 lect, 2 lab-rec hrs per wk)
A/D and D/A conversion, Sampling Theorem DFT and FFT, analog and digital filter design, simulation, real-time micro- and minicomputer control.

ME 5283. INDUSTRIAL INSTRUMENTATION AND AUTOMATIC CONTROL. (4 cr; prereq IT or grad student, 3201 or equiv; 4 lect hrs per wk)
Basic theory of linear feedback control systems. Transfer function representation of electromechanical, pneumatic, and hydraulic components. Industrial automatic controllers. Root-locus and frequency-response methods of analysis and design.

ME 5284. CONTROL SYSTEMS. (4 cr; prereq IT or grad student, 5283 or equiv; 4 lect hrs per wk)
State-space analysis of discrete-time and continuous-time control systems. Z-transform method. Liapunov stability analysis. Controllability and observability. Introduction to optimal control and adaptive control.

ME 5285. CONTROL SYSTEMS LABORATORY. (2 cr; prereq IT or grad IT major, 5283 or equiv)
Experiments designed to illustrate and apply control theory to mechanical engineering systems. Measurement techniques, calibration, timing of controls, characterization of sensors and control circuits.

ME 5288. MODELING AND SIMULATION OF DYNAMIC SYSTEMS. (4 cr; prereq IT or grad student, 5283 or equiv; 3 lect, 1 lab hrs per wk)
Generalized approach to developing models for describing complex dynamic interactions between mechanical, electrical, fluid, and thermal systems. Analog and digital simulation. Applications to electromechanical devices, transducers, hydraulic power and thermofluid systems.

ME 5330. HEAT TRANSFER LABORATORY. (2 cr; prereq upper div ME, 5342)
Measurement and analysis of various modes of heat transfer: conduction, natural and forced convection, radiation. Heat transfer analog, temperature measurement, study of heat transfer in representative engineering systems.

ME 5342. HEAT TRANSFER. (4 cr; prereq upper div IT or forest product or grad student, 3301, AEM 3200 or CE 3400; 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.

ME 5343. INTRODUCTION TO THERMAL DESIGN. (4 cr, prereq upper div IT or grad student, 5342, 5254 or equiv; 4 lect hrs per wk)
Elements of thermal design. Developments of design philosophy and governing relations for thermal configurations, including barriers and enclosures, longitudinal, radial and pin-fins, longitudinal fin arrays. Case studies from diverse thermal application areas, e.g., furnaces and ovens, HVAC systems, solar energy use, electronic equipment.

ME 5344. THERMODYNAMICS OF FLUID FLOW. (4 cr, §AEM 5201; prereq IT or grad student, AEM 3200 or CE 3400; 4 lect hrs per wk)
Compressible flow of gases in engineering systems such as nozzles, ducts, combustion chambers, ramjets, pipelines. Isentropic flow in variable area passages. One-dimensional discontinuities. Flow with wall friction, heat transfer, and mass transfer.

ME 5345. HEAT TRANSFER IN ELECTRONIC EQUIPMENT. (4 cr; prereq IT or grad student, 5342; 3 lect, 1 rec hrs per wk)
Development and application of analytical models of thermal phenomena occurring in electronic equipment. Thermal characteristics and thermal failure modes of microelectronics components. Packaging configurations used for various microelectronic applications.

ME 5346. INTERMEDIATE HEAT TRANSFER. (4 cr; prereq upper div IT or grad student, 5342; 4 lect hrs per wk)
Heat transfer fundamentals related to applications. Conduction across thermal contacts, through composite materials, and in the unsteady state. Convection in complex fluid flows. Simple turbulence models. Phase change processes (boiling, condensation, melting, freezing). Radiation between surfaces and through participating media. Mass transfer fundamentals and applications; analogy between heat and mass transfer.

ME 5351. COMPUTATIONAL HEAT TRANSFER. (4 cr; prereq IT or grad student, 5342)
Numerical solution of heat conduction and duct flow. Use of a computer program to solve complex problems involving steady and unsteady conduction, fully developed flow and heat transfer in ducts, and other special applications. Case studies to illustrate design optimization.

ME 5360. PLASMA-AIDED MANUFACTURING. (4 cr; prereq upper div IT or grad student, 3301, 5342 or equiv; 3 lect, 2 rec hrs per wk)
Introduction to plasmas as a manufacturing tool. Welding and plasma spraying. Instructions from design and thermal sciences supplemented by industry practitioners.

ME 5430. INTERNAL COMBUSTION ENGINE PERFORMANCE LABORATORY. (2 cr; prereq upper div ME, 3701, 3702, AEM 3200 or CE 3400; 3303, ¶5460 recommended)
Performance and emissions from both gasoline and diesel internal combustion engines are measured for a range of engine operating conditions.

ME 5432. STEAM POWER LABORATORY. (2 cr; prereq upper div ME, 3303, 3701, 3702, AEM 3200 or CE 3400)
The thermodynamic variables affecting the performance of a steam turbine-paper power cycle; analyzed as a function of cycle and configuration changes.

ME 5433. COMPRESSOR, COMBUSTOR, AND TURBINE LABORATORY. (2 cr; prereq upper div ME, 3303, 3701, 3702, AEM 3200 or CE 3400)
Measuring the efficiency of three different types of compressors and two types of combustor-driven turbines. Combustors analyzed for exhaust composition and combustion efficiency.

ME 5442. VAPOR CYCLE POWER SYSTEMS. (4-5 cr [1-cr term paper option]; prereq IT or grad student, 3303; 4 lect hrs per wk)
Vapor cycle analysis, regeneration, reheat, compound cycle modifications, combined gas turbines vapor cycle systems and binary systems. Combustion problems, solar, nuclear, and unusual energy sources for space power systems. A variety of configurations are evaluated using a steam cycle computer code.

ME 5443. TURBOMACHINERY. (4-5 cr [1- or 2-cr term paper option]; prereq IT or grad student, 3301 or equiv; 3 lect hrs per wk)
Thermodynamic analysis of energy transfer between fluid and rotor; dimensional analysis; principles of axial, mixed, and radial flow pumps, fans, compressors and turbines; cascade performance; computer flow simulations; applications to propulsion systems and power plants.

ME 5446. AN INTRODUCTION TO COMBUSTION. (4 cr; prereq IT or grad student, 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.

ME 5455. ROCKET PROPULSION. (3-5 cr [1- or 2-cr term paper option]; prereq IT or grad student, 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.

ME 5460. INTERNAL COMBUSTION ENGINES. (4 cr; prereq IT or grad student, 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.

ME 5461. INTERNAL COMBUSTION ENGINE MODELING. (4-5 cr [1-cr term paper option]; prereq IT or grad student, 5460 or equiv; 4 lect hrs per wk)
Traditional alternate fuels; engine lubrication and friction; engine emissions and measurement techniques; turbocharging, heat transfer and cooling; computer-based cycle modeling.

ME 5462. GAS TURBINES. (4 cr; prereq IT or grad student, 3301 or equiv; 4 lect hrs per wk)
Gas turbine cycles, regeneration, reheat, and inter-cooling. 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.

ME 5480. BIOLOGICAL FLUID FLOW. (3-4 cr [1-cr term paper option]; prereq IT or grad student, CE 3400, AEM 3200 or equiv; 3 lect hrs per wk)
Rheology and fluid dynamics of biological fluids. Blood flow, biological pumping, self-propelled particles, unusual viscoelastic behavior of biological fluids, and other fluid motions.

ME 5603. THERMAL ENVIRONMENTAL ENGINEERING. (4 cr; prereq IT or grad student, 3303, 5342 or equiv; 4 lect hrs per wk)
Thermodynamic properties of moist air; psychrometric chart applications; solar radiation; heat and moisture transmission through structures; human thermal comfort and indoor air quality; heating, cooling and ventilating systems and controls.

ME 5604. HEATING AND COOLING LOADS IN BUILDINGS. (4 cr; prereq 5603; 4 lect hrs per wk)
Transient heat transfer through structures; lighting and other internal gains; ventilation; winter and summer loads; seasonal energy estimation methods; computer simulation programs; codes and standards.

ME 5605. REFRIGERATION AND AIR CONDITIONING SYSTEMS. (4 cr; prereq IT or grad student, 3303; 4 lect hrs per wk)
Vapor compression and absorption refrigeration systems; heat pumps; heat exchangers; piping and duct layout and sizing; operations and control of building air conditioning systems.

ME 5609. AIR POLLUTION. (4 cr; prereq upper div IT or grad student; 4 lect hrs per wk)
Air pollution sources, atmospheric transport, transformations and fate. Air pollution meteorology, dispersion, and models. Basic chemistry of secondary pollutant formation, aerosol growth, air pollutant visibility relationships. Standards and regulations.

ME 5610. AIR POLLUTION CONTROL. (4 cr; prereq IT or grad student, 3303; 4 lect hrs per wk)
Study of control devices and techniques for gases and particulate emissions from stationary and mobile sources. Topics include cyclones, electrostatic precipitators, bag houses, wet and dry scrubbers, combustion modification, and alternate fuels.

ME 5613. PRINCIPLES OF PARTICLE TECHNOLOGY. (4 cr; prereq IT or grad student, 3303; 4 lect hrs per wk)
Definition, theory, and measurement of particle properties, particle statistics, fluid dynamics, optical, electrical, and thermal behavior of particles.

ME 5614. PRINCIPLES OF PARTICLE TECHNOLOGY. (4 cr; prereq IT or grad student, 5613; 4 lect hrs per wk)
Gas cleaning, particle transport, comminution, classification, surface properties, packed beds, powder behavior, and miscellaneous topics.

ME 5616. AEROSOL MEASUREMENT. (2 cr; prereq IT or grad student, 5613, 5614 or #; 3 lect-lab hrs per wk)
Principles of aerosol measurement. Modern aerosol instrumentation. Topics include optical techniques; inertial collectors; electrical mobility techniques; Beta attenuation; and piezoelectric mass sensing techniques, condensation nuclei counters, and diffusion batteries.

ME 5617. ADVANCED AEROSOL MEASUREMENT. (4 cr; prereq IT or grad student, 5613 or #)
Fundamental principles and techniques of airborne particle measurement. Modern aerosol instrumentation: inertial collectors, optical particle counters, differential mobility particle sizer, condensation nucleus counters, aerodynamic particle sizer. Aerosol generation and instrument calibration. Aerosol measurement in clean room and source emission measurement. Data analysis and interpretation.

ME 5620. CLEAN ROOM TECHNOLOGY AND PARTICLE MONITORING. (4 cr; prereq IT or grad student, 3303 or #; 3 lect, 2 lab hrs per wk)
Fundamentals of clean room technology for microelectronics manufacturing; particle mechanics and filtration; filter performance and testing; airborne and liquid-borne particulate contaminate; optical particle counters, condensation nucleus counter and wafer surface scanner; clean room design and operation; exhaust ventilation; high purity gas and water supply systems.

ME 5630. THERMAL ENVIRONMENTAL ENGINEERING SENIOR LABORATORY. (2 cr; prereq upper div ME, 3701, 3702, 5603 or ¶5603)
Experiments in psychrometrics, refrigeration, air conditioning, solar energy, and other topics related to refrigeration and building heating and cooling.

ME 5712. SOLAR ENERGY UTILIZATION. (4 cr; prereq IT or grad student, 3303, 5342; 4 lect hrs per wk)
History and potential of solar energy use; 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.

ME 5741-5742. INDUSTRIAL ASSIGNMENT AND DESIGN PROJECT. (4 cr per qtr; prereq 3742 for 5741, 5741 for 5742)
Solution of system design problems that require development of criteria, evaluation of alternatives, and generation of a preliminary design. Final report emphasizes design communication and describes design decision process, analysis, and final recommendations.

ME 5990. TOPICS IN MECHANICAL ENGINEERING. (4 cr [may be repeated for cr]; prereq upper div IT or grad student, submission of permission form, #)
Specialized topics within various areas of mechanical engineering. Emphasis on topics of current interest. Topics vary quarterly.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

ME 8190. MECHANICAL ENGINEERING GRADUATE SEMINAR

ME 8203. ADVANCED PLANAR LINKAGE SYNTHESIS

ME 8210. ADVANCED VIBRATION ENGINEERING

ME 8211-8212-8213. APPLIED DYNAMICS

ME 8221. ADVANCED COMPUTER GRAPHICS TOPICS

ME 8225. FINITE ELEMENT ANALYSIS

ME 8226. FINITE ELEMENT METHODS FOR NONLINEAR/LINEAR TRANSIENT DYNAMIC PROBLEMS

ME 8227. THE FINITE ELEMENT METHOD IN METAL FORMING PROCESSES

ME 8243. PHOTOELASTICITY

ME 8280. MULTIVARIABLE CONTROL SYSTEMS I

ME 8281. MULTIVARIABLE CONTROL SYSTEMS II

ME 8310. ADVANCED THERMODYNAMICS

ME 8311. STATISTICAL AND NONEQUILIBRIUM THERMODYNAMICS

ME 8326. BOILING HEAT TRANSFER AND MULTIPHASE FLOW

ME 8330. CONDUCTION

ME 8331. CONVECTION

ME 8332. RADIATION

ME 8333. ADVANCED THEORY OF HEAT TRANSFER

ME 8334. TURBULENT CONVECTION

ME 8350. ADVANCED FLUID THERMODYNAMICS

ME 8351. COMPUTATION OF FLUID FLOW AND HEAT TRANSFER

ME 8352. ADVANCED COMPUTATION OF FLUID FLOW AND HEAT TRANSFER

ME 8353. COMPUTATION OF BOUNDARY LAYER FLOWS

ME 8360-8361-8362. INTRODUCTION TO PLASMA TECHNOLOGY

ME 8370. EXPERIMENTAL METHODS IN HEAT TRANSFER

ME 8372. OPTICAL DIAGNOSTICS OF FLOW SYSTEMS

ME 8442. ADVANCED POWER PLANTS

ME 8443. APPLIED THERMODYNAMICS I

ME 8444. APPLIED THERMODYNAMICS II

ME 8445. APPLIED THERMODYNAMICS III

ME 8446. ENERGY TRANSPORT IN CHEMICALLY REACTING GASES

ME 8447. MASS TRANSFER IN CHEMICALLY REACTING GASES

ME 8448. ATOMIZATION, VAPORIZATION, AND MIXING

ME 8450. DYNAMICS OF HIGH SPEED ENGINES

ME 8453. ADVANCED GAS TURBINES AND JET PROPULSION

ME 8455. ADVANCED ROCKET PROPULSION

ME 8613. FUNDAMENTALS OF AEROSOL BEHAVIOR

ME 8701-8702. DESIGN STUDIES IN ENGINEERING I-II

ME 8770-8771-8772. MECHANICAL ENGINEERING RESEARCH

ME 8773-8774-8775. GRADUATE SEMINAR

ME 8800. MODERN DEVELOPMENT IN MECHANICAL ENGINEERING

Physics (Phys)

Phys 1001f,w,s, su. THE PHYSICAL WORLD. (4 cr [no cr for IT students], §any physics courses; prereq one yr high school algebra; 4 class hrs per wk)
Fundamental laws and principles governing the physical world, discussed in the context in which they are encountered in modern science and technology. Associated lab is 1005.

Phys 1005f,w,s, su. PHYSICS LABORATORY. (1 cr [no cr for IT students]; prereq 1001 or ¶1001; 2 lab hrs per wk)
Lab experiments offered in conjunction with 1001.

Phys 1041f,w,su,CEE-1042w,s,su,CEE. INTRODUCTORY PHYSICS. (5 cr per qtr; prereq high school algebra and plane geometry; trigonometry recommended; 4 lect, 1 rec, 2 lab hrs per wk)
Lectures, recitation, and lab sessions. Primarily for students interested in topics useful in technical areas. Fundamental principles of physics in context of the everyday world. Use of kinematics, dynamics, and conservation principles with quantitative and qualitative problem-solving techniques to understand phenomena of mechanics, electromagnetism, and the structure of matter.

Phys 1104f-1105w-1106s. GENERAL PHYSICS. (4 cr per qtr [no cr for IT students]; prereq high school calculus or Math 1142 or equiv, high school trigonometry or Math 1008 or Math 1151, ¶1107 for 1104, ¶1108 for 1105, ¶1109 for 1106; 4 lect, 1 quiz hrs per wk)
Fundamental principles of physics, primarily for premedical and biological science students. Description of motion, forces, conservation principles, fields and the structure of matter. *1104:* Forces and their effects. *1105:* Heat, electricity, magnetism. *1106:* Waves, light, modern physics.

Phys 1107f-1108w-1109s. GENERAL PHYSICS LABORATORY. (1 cr per qtr; prereq ¶1104 for 1107, ¶1105 for 1108, ¶1106 for 1109 or #; 2 lab hrs per wk)
Lab exercises.

Phys 1251f,w,s,su,-1252f,w,s,su,-1253f,w,s,su,-1254f,w. GENERAL PHYSICS I-IV. (4 cr per qtr, §1451H-1452H-1453H-1454H; prereq Math 1251 or ¶Math 1251 for 1251, Math 1252 or ¶Math 1252 for 1252, Math 1261 or ¶Math 1261 for 1253; 1 quiz hr as needed, 3 lect, 1 rec, 2 lab hrs per wk for 1251, 1252, 1253 and 4 lect hrs per wk for 1254)
Calculus-level general physics course emphasizing the use of fundamental principles to solve quantitative problems. Description of motion, forces, conservation principles, fields, probability, and the structure of matter. *1251:* Mechanics. *1252:* Mechanics, thermal and statistical physics. *1253:* Electricity and magnetism. *1254:* Waves, relativity, the atomic structure of matter.

Phys 1451Hf-1452Hw-1453Hs-1454Hf (formerly 1411H-1421H-1431H-1441H). HONORS PHYSICS I-IV. (4 cr per qtr, §1251-1252-1253-1254; prereq selection for IT honors curriculum or consent of IT Honors Office; 3 lect, 1 rec, 2 lab hrs per wk)
Comprehensive calculus-level general physics course for honors students. Newtonian principles of mechanics, electromagnetic forces and fields, introduction to 20th-century physics, thermal and other properties of matter.

Phys 1911-1912. LABORATORY-BASED PHYSICS FOR TEACHERS. (4 cr per qtr [no cr for IT students]; 6 lab hrs per wk)
For students intending to be elementary education majors. Topics applied to elementary school curriculum include the Earth's motion, properties of matter, heat and temperature, kinematics, and electric current.

Phys 3501. MODERN PHYSICS. (4 cr [no cr for physics majors], §3512-3513; prereq 1253 or 1453, Chem 1052, Math 3261)
Thermal and statistical physics concepts; elementary quantum mechanics with examples from thermal radiation, atomic and molecular structure, and solid-state physics.

Phys 3512w-3513s. QUANTUM PHYSICS I-II. (3 cr per qtr; prereq 1253 or 1291 or 1341 or 1441 or 1453, Math 3252 or ¶Math 3252; 1254 or 1454 recommended; 3 class hrs per wk)
Introduction to quantum mechanics and selected topics form its application to atomic, molecular, condensed-matter, nuclear, elementary-particle, and statistical physics. Associated labs are 3515-3516.

Phys 3515w,3516s. MODERN PHYSICS LABORATORY. (2 cr; prereq 3512 or ¶3512 or 3501 or ¶3501; 1 lect, 3 lab hrs per wk)
Lab experiments in atomic, solid state, and nuclear physics offered in conjunction with 3512-3513.

3601f SPECIAL RELATIVITY. (3 cr; prereq 1253 or 1453; 3 class hrs per wk)
Introduction to special relativity.

Phys 3970. DIRECTED STUDIES. (1-5 cr per qtr; prereq #, Δ)
Independent, directed study in physics in areas arranged by the student and a faculty member.

Phys 5021f-5022w. INTRODUCTION TO ANALYTIC MECHANICS. (4 cr per qtr; prereq Math 3261 or equiv; 4 lect hrs per wk)
Analytical course in Newtonian mechanics. Mathematics beyond the prerequisites developed as required.

Phys 5023s-5024f. INTRODUCTION TO ELECTRIC AND MAGNETIC FIELDS. (4 cr per qtr; prereq Math 3261 or equiv; 4 lect hrs per wk)
Classical theory of electromagnetic fields using vector algebra and vector calculus.

Phys 5031f-5032w-5033s. TOPICS IN MATHEMATICAL PHYSICS. (4 cr per qtr; prereq two 5xxx math courses; 4 lect hrs per wk)
Mathematical techniques for physics. Application of mathematical methods to physical problems.

Phys 5051f-5052w-5053s. CLASSICAL PHYSICS. (4 cr per qtr; prereq 5022, 5024, advanced calculus or #; 4 lect hrs per wk)
Classical mechanics, special relativity, and classical electrodynamics. Applications of advanced mathematical techniques.

Phys 5061f. COMPUTATIONAL METHODS IN THE PHYSICAL SCIENCES I. (4 cr, §Ast 5061; prereq upper div or grad status or #; 2 lect, 6 lab hrs per wk)
Problem solving in the physical sciences with computer programs. Numerical methods; mapping problems onto computational algorithms. Arranged lab at scientific computer workstation.

Phys 5062w. COMPUTATIONAL METHODS IN THE PHYSICAL SCIENCES II. (4 cr, §Ast 5062; prereq 5061 or Ast 5061 or #; 2 lect, 6 lab hrs per wk)
Advanced techniques in computer simulation; examples from classical statistical mechanics, classical electrodynamics, and fluid dynamics. Computer experiments illustrating these techniques with graphics.

Phys 5101f-5102w. INTRODUCTION TO QUANTUM MECHANICS. (4 cr per qtr; prereq 3513; 4 lect hrs per wk)
Mathematical techniques of quantum mechanics. Schrödinger equation and simple applications, general structure of wave mechanics, operator methods, perturbation theory, radiation of atoms.

Phys 5121f. METHODS OF EXPERIMENTAL PHYSICS I. (5 cr; prereq 3513, 3516 or #; 3 lect, 4 lab hrs per wk)
Contemporary experimental techniques. Introduction to modern analog and digital electronics from an experimental viewpoint.

Phys 5122w. METHODS OF EXPERIMENTAL PHYSICS II. (4 cr; prereq 5121 or #; 2 lect, 6 lab hrs per wk)
Contemporary experimental techniques. Use of computers for data acquisition and experimental control. Experiments with data analysis.

Phys 5123s. METHODS OF EXPERIMENTAL PHYSICS III. (4 cr; prereq 5122 or #; 2 lect, 6 lab hrs per wk)
Contemporary experimental techniques. Students design and execute an experimental project. Lectures on specialized topics emphasizing research labs.

Phys 5124. EXPERIMENTAL PROJECT. (Cr ar; prereq 5123, #)
Research project in a physics area of contemporary interest. Project must be approved by faculty coordinator before registration.

Phys 5151f-5152w-5153s. QUANTUM MECHANICS. (4 cr per qtr; prereq 5102 or equiv, advanced calculus or #; 4 lect hrs per wk)
Development from first principles. Application of Schrödinger equation, matrix representations, approximation methods.

Phys 5162. INTRODUCTION TO PLASMA PHYSICS. (4 cr; prereq 5022, 5024 or #; offered alt yrs)
Magnetohydrodynamics and properties of collisionless plasmas, applications to magnetic field of Earth and sun and to plasma confinement. Transport phenomena and effects of collisions.

Phys 5201f,w-5202w. THERMAL AND STATISTICAL PHYSICS. (4 cr per qtr; prereq 3513 or equiv; 4 lect hrs per wk)
Principles of thermodynamics and statistical mechanics and selected topics from their application to kinetic theory; transport theory and phase transitions.

Phys 5211s. INTRODUCTORY SOLID-STATE PHYSICS. (4 cr; prereq 5101, 5202 or equiv; 4 lect hrs per wk)
Properties of solids. Topics include vibrational and electronic properties of solids, diffraction of waves in solids and electron band structure. Other possible topics include optical properties, magnetic phenomena, superconductivity.

Phys 5231f-5232w-5233s. INTRODUCTION TO SOLID-STATE PHYSICS. (4 cr per qtr; prereq grad or advanced undergrad in physical science or engineering, 1254, 3512 or #; 4 lect hrs per wk)
Principles of solid physics for scientists and engineers. Crystal structure and binding; X-ray and neutron diffraction; phonons; thermal and dielectric properties of insulators; the free-electron model and band structure of metals; semiconducting behavior and magnetism. Other possible topics include superconductivity, ferroelectricity, optical phenomena, surface and interface properties, and departures from crystalline order.

Phys 5301s. INTRODUCTION TO NUCLEAR PHYSICS. (4 cr; prereq 5101 or equiv; 4 lect hrs per wk)
Structure of atomic nuclei; single-particle and collective models; interactions between elementary particles and nuclei and nucleus-nucleus interactions from very low up to relativistic energies; tests of fundamental conservation laws; fission and fusion reactions; astrophysical applications. Survey for nonspecialists and a first course for those planning to specialize in nuclear physics.

Phys 5371s. INTRODUCTION TO ELEMENTARY PARTICLE PHYSICS. (4 cr; prereq 5101 or equiv; 4 lect hrs per wk)
Properties and interactions of the fundamental constituents of nature. Survey for nonspecialists and those intending to specialize in elementary particle physics.

Phys 5400H. JUNIOR HONORS SEMINAR. (1 cr; prereq upper div IT or CLA honors student, #; 1½ sem hrs per wk; may be taken no more than three times)
Seminar for upper division physics majors in the honors program, designed to prepare students for senior honors thesis projects and provide guidance in choice of future careers.

Phys 5401. INTRODUCTION TO CONTEMPORARY PROBLEMS IN COSMIC RAY AND SPACE PHYSICS. (4 cr; prereq #; primarily for students specializing in other branches of physics; offered alt yrs)
Astrophysics of energetic particles and photons. Cosmic rays and solar energetic particles. Detection and identification of high energy particles and photons. Interactions with matter and magnetic fields in space. Acceleration, modulation, propagation.

Phys 5410H. SENIOR HONORS SEMINAR. (1 cr; prereq upper div IT or CLA honors student, #; 1½ sem hrs per wk; may be taken no more than three times)
A seminar for upper division physics majors in the honors program who are carrying out senior honors thesis projects.

Phys 5461. PHYSICS AND CHEMISTRY OF THE EARTH'S UPPER ATMOSPHERE. (4 cr; prereq general physics, calculus; offered alt yrs; 4 lect hrs per wk)
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.

Phys 5551f. TOPICS IN PHYSICS FOR BIOLOGY AND MEDICINE: MECHANICS AND MOLECULAR PHYSICS. (5 cr per qtr; prereq general physics, calculus; offered alt yrs)
Statics (forces in bones and joints). Exponential growth and decay. Statistical physics (entropy, reversibility, Boltzmann factor and Nernst equation, Brownian movement, free energy). Diffusion, bulk flow, and osmosis.

Phys 5552w. TOPICS IN PHYSICS FOR BIOLOGY AND MEDICINE: ELECTRICITY AND SIGNALS. (5 cr per qtr; prereq general physics, calculus; offered alt yrs)
Electricity and circuits (electrocardiogram, networks, nerve conduction); transducers, amplifiers; oscillators; feedback control; signal analysis (Fourier analysis, correlation functions, power spectra).

Phys 5553s. TOPICS IN PHYSICS FOR BIOLOGY AND MEDICINE: LIGHT, ATOMS, AND NUCLEI. (5 cr per qtr; prereq general physics, calculus; offered alt yrs)
X-rays (production, absorption, dosimetry). Nuclear medicine. Magnetic resonance imaging.

Phys 5561. MAGNETISM: PHYSICS, GEOPHYSICS, AND ENGINEERING. (3 cr, §EE 5561, §Geo 5561; prereq 1253 or 1453; 3 lect hrs per wk)
Elementary statistical mechanics, rock magnetism, micromagnetic modeling. Applications of magnetism in geophysics, biomagnetism, magnetic sensors, and recording.

Phys 5801s. MODERN OPTICS. (4 cr; prereq 5024 or #; 4 lect hrs per wk; offered alt yrs)
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.

Phys 5805. CONTEMPORARY OPTICS. (4 cr; prereq #; 4 lect hrs per wk)
Fundamentals of lasers, including propagation of Gaussian beams, optical resonators, theory of laser oscillation, electro-optic and acousto-optic modulation, and nonlinear optics.

Phys 5911-5912. CONCEPTS IN PHYSICS. (4 cr per qtr; prereq general physics or #; 3 lect, 2 lab hrs per wk)
Overview of physics with emphasis on 20th-century developments. Primarily for secondary teachers and science majors wanting a summary review of physics.

Phys 5924. HISTORY OF 19TH-CENTURY PHYSICS. (4 cr, §HSci 5924; prereq general physics or #)
Experimental and theoretical discoveries in 19th-century physics (wave theory of light, atomic theory, heat, thermodynamics and statistical mechanics, electromagnetism and field theory) within context of educational, institutional, and political developments in Europe and the United States.

Phys 5925. HISTORY OF 20TH-CENTURY PHYSICS. (4 cr, §HSci 5925; prereq general physics or #)
Experimental and theoretical discoveries in 20th-century physics (birth of modern physics, special theory of relativity, old and new quantum theories) within context of educational, institutional, and political developments in Europe and the United States.

Phys 5940su,CEE. PHYSICS FOR HIGH SCHOOL TEACHERS: EXPERIMENTAL FOUNDATIONS AND HISTORICAL PERSPECTIVES. (4 cr per qtr [may be repeated for cr; no cr for physics grad or grad physics minor]; prereq completion of summer session 5940)
For physics and physical sciences teachers. Improves understanding of electricity and shows how the history of science can bring more activity and fun into teaching. Teachers follow the development of ideas, repeat historical experiments, and learn investigation techniques.

Phys 5950. COLLOQUIUM SEMINAR. (Cr ar; primarily for beginning grads and advanced undergrads in physics; prereq Δ; S-N only)
Colloquium of the School of Physics and Astronomy.

Phys 5961CEE. PHYSICAL SCIENCE FOR ELEMENTARY SCHOOL TEACHERS. (1-4 cr, [may be repeated for cr; no cr for physics undergrad or grad or for undergrad or grad physics minor]; prereq elementary school teacher recommended by participating school district)
Development of in-depth understanding of physics topics relevant to elementary school teaching. Focuses on synthesis of mathematical concepts, problem-solving strategies, and model building to explain the physical world.

Phys 5970. DIRECTED STUDIES. (1-5 cr; prereq #, Δ)
Independent, directed study in physics in areas arranged by the student and a faculty member.

Phys 5980. RESEARCH SEMINAR. (1 cr; primarily for beginning grads and advanced undergrad majors in physics; 1 sem hr per wk)
Introduction to the research activities of the School of Physics and Astronomy.

Phys 5990. DIRECTED RESEARCH. (Cr ar; prereq 3rd yr, Δ)
Problems, experimental or theoretical, of special interest to students. Written reports.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

Phys 8081-8082. GENERAL RELATIVITY

Phys 8121. ADVANCED QUANTUM MECHANICS

Phys 8122. RELATIVISTIC QUANTUM MECHANICS

Phys 8123. RELATIVISTIC QUANTUM FIELD THEORY

Phys 8131. SYMMETRY AND ITS APPLICATIONS TO PHYSICAL PROBLEMS

Phys 8161. ATOMIC AND MOLECULAR STRUCTURE

Phys 8163-8164. PLASMA PHYSICS

Phys 8165. ADVANCED TOPICS IN PLASMA PHYSICS

Phys 8200. SEMINAR: CONDENSED MATTER PHYSICS

Phys 8211. EQUILIBRIUM STATISTICAL MECHANICS

Phys 8212. TRANSPORT THEORY

Phys 8216. MANY-BODY THEORY

Phys 8221-8222-8223. SOLID-STATE PHYSICS

Phys 8232. MAGNETISM

Phys 8233. SUPERCONDUCTIVITY

Phys 8234. TECHNIQUES OF LOW-TEMPERATURE PHYSICS

Phys 8235. LIQUID AND SOLID HELIUM

Phys 8238. ADVANCED TOPICS IN SOLID-STATE AND LOW-TEMPERATURE PHYSICS

Phys 8300. SEMINAR: NUCLEAR PHYSICS

Phys 8311. NUCLEAR STRUCTURE

Phys 8312. NUCLEAR REACTIONS

Phys 8313. RELATIVISTIC NUCLEAR MANY-BODY THEORY

Phys 8321. ADVANCED TOPICS IN NUCLEAR PHYSICS

Phys 8360. SEMINAR: MASS SPECTROSCOPY

Phys 8370. SEMINAR: ELEMENTARY PARTICLE PHYSICS

Phys 8371-8372-8373. ELEMENTARY PARTICLE PHYSICS

Phys 8380. ADVANCED TOPICS IN ELEMENTARY PARTICLE PHYSICS

Phys 8381-8382-8383. MODERN QUANTUM FIELD THEORY AND ITS APPLICATIONS

Phys 8400. SEMINAR: SPACE PHYSICS

Phys 8411-8412. COSMIC RAY AND SPACE PHYSICS

Phys 8421-8422. SOLAR AND MAGNETOSPHERIC PHYSICS

Phys 8500. PLAN B PROJECT

Phys 8950. SEMINAR: PROBLEMS OF PHYSICS TEACHING AND HIGHER EDUCATION

Phys 8990. RESEARCH IN PHYSICS

Statistics (Stat)

Stat 1001. INTRODUCTION TO IDEAS OF STATISTICS. (4 cr; prereq high school algebra)
Controlled vs. observational studies; presentation and description of data; correlation and causality; sampling; accuracy of estimates; tests.

Stat 3011-3012. STATISTICAL ANALYSIS. (4 cr per qtr, prereq college algebra)
Descriptive statistics; elementary probability; estimation; one- and two-sample tests; correlation; introduction to regression; ANOVA; randomized blocks; multiple comparisons; factorial experiments; multiple regression; goodness of fit; nonparametric methods; contingency tables; selected topics.

Stat 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.

Stat 5021. STATISTICAL ANALYSIS. (5 cr, §3012; prereq college algebra or #)
Intensive version of 3011-3012; primarily for graduate students needing statistics as a research technique.

Stat 5091. STATISTICAL METHODS FOR QUALITY IMPROVEMENT. (4 cr; prereq 3012 or 3091 or 5021 or 5122 or 5132, Math 1252)
Application of statistical concepts of random variability and sampling, statistical process control, Shewhart and accumulative charting, analysis of plant data, applications of trend surface analysis, analysis of variance and design of experiments, quality improvement by reduction of random variability.

Stat 5121f-5122w. THEORY OF STATISTICS. (5 cr per qtr, §5131-5132-5133; prereq Math 1252)
Univariate and multivariate distributions, law of large numbers, sampling, likelihood methods, estimation and hypothesis testing, regression and analysis of variance, confidence intervals, distribution-free methods.

Stat 5131f-5132w-5133s. THEORY OF STATISTICS. (4 cr per qtr, §5121-5122; prereq Math 3252)
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- and two-sample problems, regression, analysis of variance. Treatment more mathematical than that in 5121-5122.

Stat 5201w. SAMPLING METHODOLOGY IN FINITE POPULATIONS. (4 cr; prereq 3091 or 5021 or 5121 or #) Simple random, systematic, stratified, and unequal probability sampling. Ratio and regression estimation. Multistage and cluster sampling.

Stat 5271. BAYESIAN DECISION MAKING. (4 cr; prereq ¶5122 or ¶5132) Axioms for personal probability and utility. Elements of statistical decision theory. Bayesian analysis of linear models.

Stat 5301f,s. DESIGNING EXPERIMENTS. (5 cr, §5163; prereq 3012 or 5021 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.

Stat 5302f,s. APPLIED REGRESSION ANALYSIS. (5 cr, §5161; prereq 3012 or 5021 or 5133 or #) Simple, multiple, and polynomial regression. Estimation, testing, and prediction. Stepwise and other numerical methods; examination of residuals; weighted least squares; nonlinear models; response surface. Experimental research and economic applications.

Stat 5401s. INTRODUCTION TO MULTIVARIATE METHODS. (4 cr; prereq 5133 or 5302) 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.

Stat 5421. ANALYSIS OF CATEGORICAL DATA. (4 cr, §5162; prereq 3012 or 5021 or 5133 or #) Varieties of categorical data, cross-classifications and contingency tables, tests for independence. Multidimensional tables and log-linear models, maximum likelihood estimation, and tests of goodness of fit. Analysis of Markov chain data. Smoothing counts.

Stat 5601w. NONPARAMETRIC METHODS. (4 cr; prereq 5021 or 5122 or 5132 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.

Stat 5890. SENIOR PAPER. (2 cr; prereq sr Stat major) Paper on specialized area, consulting project, or original computer program. Directed study satisfies senior project requirement for majors.

Stat 5900. TUTORIAL COURSE. (Cr ar; prereq #) Study in areas not covered by regular offerings. Directed study.

Stat 5911, 5912, 5913. TOPICS IN STATISTICS. (3 cr per qtr [may be repeated for cr with Δ]; prereq 3091 or 5021, #) Topics vary.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

Stat 5151-5152-5153. THEORY OF STATISTICS.

Stat 5161-5162-5163. APPLIED STATISTICAL METHODS.

Stat 8151-8152-8153. MATHEMATICAL STATISTICS

Stat 8162. COMPUTATIONAL STATISTICAL METHODS

Stat 8171-8172-8173. THEORY OF INFERENCE

8191-8192. LARGE-SAMPLE THEORY

Stat 8221. TOPICS IN SAMPLING

Stat 8311-8312. LINEAR MODELS

Stat 8313. TOPICS IN EXPERIMENTAL DESIGN

Stat 8321. LINEAR AND NONLINEAR REGRESSION

Stat 8331. STATISTICAL COMPUTING

Stat 8401. TOPICS IN MULTIVARIATE METHODS

Stat 8411-8412. MULTIVARIATE ANALYSIS

Stat 8431. THEORY OF CATEGORICAL DATA ANALYSIS

Stat 8501-8502. INTRODUCTION TO STOCHASTIC PROCESSES WITH APPLICATIONS

Stat 8511-8512. TIME SERIES ANALYSIS

Stat 8601. TOPICS IN ROBUST METHODS

Stat 8611-8612. NONPARAMETRIC INFERENCE

Stat 8731-8732. STATISTICAL DECISION THEORY

Stat 8751-8752. SEQUENTIAL ANALYSIS

Stat 8801. STATISTICAL CONSULTING

Stat 8900. STUDENT SEMINAR

Stat 8901. DIRECTED READINGS AND RESEARCH

Stat 8931-8932-8933-8934. ADVANCED TOPICS IN STATISTICS

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University Regents

Jean B. Keffeler, Minneapolis, Chair
Thomas R. Reagan, Gilbert, Vice Chair
Wendell R. Anderson, Wayzata
Julie A. Bleyhl, Madison
William E. Hogan II, Minnetonka
Hyon T. Kim, St. Anthony
Warren C. Larson, Bagley
H. Bryan Neel III, Rochester
William R. Peterson, Eagan
Jessica J. Phillips, Morris
Stanley D. Sahlstrom, St. Cloud
Patricia B. Spence, Rice

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Robert O. Erickson, Senior Vice President for Finance and Operations
Ettore F. Infante, Senior Vice President for Academic Affairs
C. Eugene Allen, Provost for Professional Studies
William R. Brody, Provost for the Academic Health Center
W. Phillips Shively, Provost for Arts, Sciences, and Engineering
McKinley Boston, Jr., Vice President for Student Development and Athletics (effective 7/1/95)
Mark L. Brenner, Acting Vice President for Research and Acting Dean of the Graduate School
Melvin George, Vice President for Institutional Relations
Mark B. Rotenberg, General Counsel

Institute of Technology Administrators

To be named, Dean
Willard Miller, Associate Dean, Finance and Planning
To be named, Associate Dean, Student Affairs
V. Rama Murthy, Director, Lower Division Programs,
Mr. and Mrs. George W. Taylor Distinguished Teaching Professor
Karen Wolterstorff, Associate to the Dean
To be named, Director,
Project Technology Power
Robert Pepin, Director, Honors
Richard Schleicher, Director, Advancement and External Relations
Sharon B. Kurtt, Director, Career Development/Placement
K. S. P. Kumar, Associate Dean, External Programs, Director, UNITE
Benjamin G. Sharpe, Director, Admissions

Institute of Technology Faculty

In the faculty listing that follows, P.E. designates licensure as a professional engineer in Minnesota.

Recipients of the Horace T. Morse-Minnesota Alumni Association Award for Outstanding Contributions to Undergraduate Education are designated by an asterisk (*).

Aerospace Engineering and Mechanics

Regents' Professor
Daniel D. Joseph, Russell J. Penrose Professor

Professor
William L. Garrard, *head*
Gordon S. Beavers
Jerald L. Ericksen, emeritus
Roger L. Fosdick
Philip G. Hodge, Jr., emeritus
C. C. Hsiao, emeritus
Richard D. James
Thomas S. Lundgren
Robert Plunkett, emeritus
Tayfun E. Tezduyar
William H. Warner
Theodore A. Wilson, *director of graduate studies*

Associate Professor
Graham V. Candler
Dale Enns (adjunct)
Perry H. Leo, *director of undergraduate studies*
Eugene Stolarik, emeritus
Lev Truskinovsky

Assistant Professor
Scott D. Abrahamson
Amy E. Alving
Gary J. Balas
Ellen K. Longmire
Thomas A. Posbergh
Thomas W. Shield
Yiyuan Zhao

Akerman Adjunct Professor of Design
Andrew Vano,
director of engineering intern program

Astronomy

Regents' Professor
Edward P. Ney

Professor
Kris Davidson
John M. Dickey
Robert D. Gehrz
Roberta M. Humphreys
Terry J. Jones, *director of undergraduate studies*
Thomas W. Jones, *chair*
Leonard V. Kuhi
Lawrence Rudnick, *director of graduate studies*
Evan D. Skillman
Paul R. Woodward

Biosystems and Agricultural Engineering

Professor
John F. Anderson, D.V.M.
Frederick G. Bergsrud
Kevin A. Janni, P.E., *director of graduate studies*
R. Vance Morey, *head*
Cletus E. Schertz

Associate Professor
Mrinal Bhattacharya
James J. Boedicker
Jonathan Chaplin, C.Eng., P.E.
Charles J. Clanton, P.E.,
director of undergraduate studies
Philip R. Goodrich, P.E.
Larry D. Jacobson, P.E.
John L. Nieber, P.E.
William F. Wilcke
Bruce N. Wilson
Jerry A. Wright, P.E.
Robert A. Young

Assistant Professor
John P. Chastain
Chang-Ho Park
Roger Ruan
John M. Shutske

Chemical Engineering and Materials Science

Regents' Professor
Rutherford Aris
L. E. Scriven

Professor
H. Ted Davis, *head*
Frank S. Bates
Robert W. Carr, Jr.
C. Barry Carter
James R. Chelikowsky
E. L. Cussler
John S. Dahler
D. F. Evans
Arnold G. Fredrickson
C. Geankoplis
William W. Gerberich
W.S. Hu
K. H. Keller
C. W. Macosko
Lanny D. Schmidt
David A. Shores
W. H. Smyrl
Matthew V. Tirrell
Michael D. Ward
John H. Weaver

Associate Professor
Jeffrey J. Derby
Alon V. McCormick
Christopher J. Palmstrom
John M. Sivertsen
Friedrich Srienc
Robert T. Tranquillo

Assistant Professor
Prodramos Daoutidis
Lorraine F. Francis
C. Daniel Frisbie
Renata M. Wentzcovitch

Chemistry

Professor
Jan Almlöf
George Barany
Paul Barbara
Victor A. Bloomfield
Doyle Britton
Peter W. Carr
John S. Dahler
H. Ted Davis
John E. Ellis, *director of graduate studies*
John F. Evans
W. Ronald Gentry, *chair*
Wayne Gladfelter
Gary R. Gray, *director of undergraduate studies*
Thomas R. Hoye
Essie Kariv-Miller
Sanford Lipsky
Hung-Wen Liu
Timothy P. Lodge
Kent Mann
Larry L. Miller

Wilmer G. Miller
Albert J. Moscowitz
Wayland E. Noland
Louis H. Pignolet
Lawrence Que, Jr.
Michael A. Rafferty
Marian Stankovich
Harold S. Swofford, Jr.
Donald G. Truhlar

Associate Professor
Steven R. Kass
Doreen G. Leopold
Kenneth R. Leopold
Scott D. Rychnovsky
William B. Tolman

Assistant Professor
Christopher J. Cramer
Mark D. Distefano
Craig J. Forsyth
Eric Munson
Karin Musier-Forsyth
Jeffrey T. Roberts
J. Ilja Siepmann
Andreas Stein
Li Sun

Civil Engineering

Professor
Steven L. Crouch, *head*
Charles Fairhurst, *Theodore Bennett Professor of Mining Engineering and Rock Mechanics*
Roger E. A. Arndt
Kenneth J. Reid
Heinz G. Stefan, *director of graduate studies*
Patrick L. Brezonik
Andrew Drescher
Steven J. Eisenreich
Cesar Farell
Theodore V. Galambos, P.E., *James L. Record Professor of Civil Engineering*
Malcolm Hepworth
Walter J. Maier, P.E.
Panos G. Michalopoulos
Gary Parker
Michael Semmens, P.E.
Charles C. S. Song
Yorgos J. Stephanedes, P.E.
Otto D. L. Strack

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Randal Barnes
Emmanuel Detournay
Daryl F. Dwyer
Efi Foufoula-Geogiou
Catherine W. French, P.E.
John S. Gulliver, P.E.
Gerald W. Johnson, *director of undergraduate studies*
Joseph T. Labuz, P.E.
David E. Newcomb, P.E., *Minnesota Surveyors and Engineers Society Miles Kersten Land Grant Professor of Civil Engineering*
Karl Smith
Raymond L. Sterling, P.E., *director of Underground Space Center, Shimizu Professor of Civil Engineering*
Henryk Stolarski
Vaughan Voller

Assistant Professor
Gary Davis
Jerome Hajjar
Carol Shield
Mark B. Snyder

Computer Science

Professor
David Du
David W. Fox
Linda Petzold
J. Ben Rosen, emeritus
Youcef Saad
Ahmed Sameh, *head*
Eugene Shragowitz
James R. Slagle
Marvin L. Stein, *director of graduate studies*
Pen-Chung Yew

Associate Professor
Daniel Boley
John Carlis
Ding-Zhu Du
Krzysztof Frankowski
Maria Gini
Ravi Janardan
Vipin Kumar
Arthur L. Norberg
Haesun Park
Ting-Chuen Pong
Shashi Shekhar, *director of undergraduate studies*
Jaideep Srivastava

Anand Tripathi
Wei-Tek Tsai

Assistant Professor
Phillip Barry
Joseph Konstan
Zhiyuan Li
Nikolaos Papanikolopoulos
John Riedl
Shanghua Teng

Earth Sciences

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Herbert E. Wright, Jr., emeritus

Professor
William E. Seyfried, Jr., *head*
E. Calvin Alexander, Jr.
Subir K. Banerjee, *director of Institute for Rock Magnetism*
Roger L. Hooke
Peter J. Hudleston
Shun Karato
Kerry Kelts, *director of Limnological Research Center*
Sally Gregory Kohlstedt
David Kohlstedt
G.B. Morey
V. Rama Murthy
Hans-Olaf Pfannkuch
Robert E. Sloan
David Southwick, *director of Minnesota Geological Survey*
James H. Stout
Frederick Swain, emeritus
Matt Walton, emeritus
Paul W. Weiblen
David A. Yuen
Tibor Zoltai, emeritus

Associate Professor
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Emi Ito
Karen Kleinspehn
Christopher Paola, *director of undergraduate studies*
Christian Teyssier

Assistant Professor
Bruce Moskowitz
Mark Person

Adjunct Professor
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Michael Jackson
Robert G. Johnson
Lecturer
Kent Kirkby

Electrical Engineering

Professor
Vernon D. Albertson, P.E.
LeRoy T. Anderson, emeritus
Frederic N. Bailey
J. Alex Carruthers, emeritus
*Paul A. Cartwright, emeritus
Stephen K. Case
Keith S. Champlin
Lorne M. Chanin, emeritus
Stephen Y. Chou
Philip I. Cohen
Robert J. Collins, emeritus
Tryphon Georgiou
Anand Gopinath
B.V. Haxby, emeritus
Jack H. Judy
Richard Y. Kain, *director of graduate studies*
Mostafa Kaveh, *head*
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Larry L. Kinney, *associate head, director of undergraduate studies*
K. S. P. Kumar
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E. Bruce Lee
Ned Mohan
Rolf K. Mueller, emeritus
Marshall I. Nathan
Allen Nussbaum, emeritus
Hendrik J. Oskam, emeritus
William T. Peria
William A. Plice, emeritus
Mahmoud Riaz
William P. Robbins
Otto H. Schmitt, emeritus
W. G. Shepherd, emeritus
Allen R. Tannenbaum
Raymond M. Warner, Jr., emeritus
Bruce F. Wollenberg

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Steven A. Campbell
Vladimir S. Cherkassky
Douglas W. Ernie

James E. Holte
Thomas S. Lee
James R. Leger
Keshab K. Parhi
Dennis L. Polla
P. Paul Ruden
Gerald E. Sobelman
Ahmed H. Tewfik
Jian G. (Jimmy) Zhu

Assistant Professor
Shantanu Dutt
Ramesh Harjani
Ted K. Higman
Gyungho Lee
David J. Lilja
Lori Lucke
Jaekyun (Jay) Moon
Matthew T. O'Keefe
Andrew Teel
Bapiraju Vinnakota

Adjunct Professor
Gregory T. Cibuzar
Barry K. Gilbert
David Grider
Michael Haase
Pramod P. Khargonekar
Daniel S. Kirschen
David R. Lamb
David S. Lo
Blaise Morton
Hjatmar (Hal) Otteson
Michael Shur
Vladimir Sololov
Frank G. Soltis
Julio C. Spinelli
Frederick M. Waltz

Mathematics

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Professor
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Stephen Agard
Greg Anderson
Donald G. Aronson
John R. Baxter
Thomas Berger
John A. Eagon
Paul Edelman
Robert Ellis
Eugene Fabes
Mark Feshbach
Avner Friedman, *director of Institute for Mathematics and Its Applications, director of Minnesota Center for Industrial Mathematics*
*Bert Fristedt
Paul Garrett
J. Gil de Lamadrid
Jay R. Goldman
Lawrence Gray
Leon W. Green
Robert Gulliver II, *associate director of Institute for Mathematics and Its Applications*
Morton Harris
Dennis Hejhal
Ettore Infante, *senior vice president and provost*
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Max A. Jodeit, Jr.
Donald Kahn
Harvey B. Keynes, *director of special projects*
N.Y. Krylov, *Ordway Professor*
Walter Littman
Mitchell Luskin
Albert Marden
Charles A. McCarthy
Richard McGehee, *director of Geometry Center*
William Messing
Norman G. Meyers
Willard Miller, Jr., *associate dean*
Richard Moeckel
Wei-Ming Ni
Johannes C. C. Nitsche
Peter Olver
Marian B. Pour-El
Karel Prikry
Edgar Reich
Peter Rejto
Joel Roberts
Mikhail Safonov
David H. Sattinger
George R. Sell
Yasutaka Sibuya
Steven I. Sperber
Dennis Stanton
David A. Storvick
Vladimir Sverak
Peter Webb
Hans Weinberger
Dennis White

Associate Professor
George U. Brauer
Ben Chow
Bernardo Cockburn
Jack Conn
David Frank
E. Gebhard Fuhrken
Lisl N. Gaal
Hillel Gershenson
Laurence R. Harper
Howard B. Jenkins
Gennady Lyubeznik
Chester L. Miracle
Wayne Richter
Charlotte Striebel

Assistant Professor
Scot Adams
Satyanad Kichenassamy
Nai-Chung Leung
John Lowengrub
Victor Reiner
John Sullivan

Mechanical Engineering

Regents' Professor
Ernst R. G. Eckert, emeritus
Richard J. Goldstein, P.E., *head, James J. Ryan Professor*
Benjamin Y. H. Liu, *Richard C. Jordan Professor*

Professor
James W. Ramsey, *associate head, director of undergraduate studies*
Sant Ram Arora
Avram Bar-Cohen
Perry L. Blackshear, Jr., emeritus
Max Donath, *director of Center for Advanced Manufacturing Design and Control*
*Arthur G. Erdman, P.E.
Edward A. Fletcher
Darrell A. Frohrib
Joachim V. R. Heberlein
*Warren E. Ibele
Richard C. Jordan, emeritus
David B. Kittelson
Thomas H. Kuehn, P.E., *director of graduate studies*
Francis A. Kulacki, *IT dean*
Tarald O. Kvålseth
Edwin T. Layton
Virgil A. Marple, *director of Co-op Program*
Peter H. McMurry
Katsuhiko Ogata
*Suhas V. Patankar
Emil Pfender, *Ernst Eckert Professor*
David Y. H. Pui, *director of China Center*
Subbiah Ramalingam
Donald R. Riley, *associate vice president and associate provost*
Yechiel Shulman, *director of Center for Technological Leadership, H.W. Sweatt chair*
Terrence W. Simon
*Ephraim M. Sparrow
Patrick J. Starr
Kim A. Stelson
Kumar K. Tamma
Benson H. Tongue, *Benjamin Mayhugh Professor*

Associate Professor
Thomas R. Chase
Jane H. Davidson
Kevin J. Dooley
William K. Durfee, *Richard and Barbara Nelson Professor*
Steven L. Girshick
Barney E. Klamecki
Charles J. Scott
Paul Strykowski

Assistant Professor
John Abraham, *Richard and Barbara Nelson Professor*
Saifallah Benjaafar, *Richard and Barbara Nelson Professor*
John C. Bischof, *Richard and Barbara Nelson Professor*
David L. Hofeldt
Shahrukh A. Irani
Susan C. Mantell, *Richard and Barbara Nelson Professor*
Jeffrey H. Vogel

Lecturer
Edward L. Barnett
Tesfahun Berhe

Physics

Professor
Marvin L. Marshak, *head*
Benjamin F. Bayman
J. Morris Blair, emeritus
John H. Broadhurst
Laurence J. Cahill, Jr., emeritus
Charles E. Campbell
Hans W. J. Courant
E. Dan Dahlberg
Dietrich K. Dehnhard
Paul J. Ellis
George D. Freier, emeritus
Stephen Gasiorowicz
Clayton F. Giese, *director of graduate studies*
Leonid Glazman
Allen M. Goldman
George W. Greenlees, emeritus
J. Woods Halley
Morton Hamermesh, emeritus
Kenneth Heller, *director of undergraduate studies*
Norton M. Hintz, emeritus
Russell K. Hobbie
Yutaka Hosotani
Cheng-Cher Huang
*Walter H. Johnson, Jr., emeritus
Joseph I. Kapusta
Paul J. Kellogg
Robert Lysak
Homer T. Mantis, emeritus
Erwin Marquit
Konrad Mauersberger, on leave
Larry McLerran
Keith A. Olive
Robert O. Pepin
Earl A. Peterson
Serge Rudaz
Keith Ruddick
Alan E. Shapiro
Mikhail Shifman
Boris Shklovskii
Roger H. Stuewer
Hiroshi Suura, emeritus
Yau-Chien Tang
Arkady Vainshtein
Oriol T. Valls
Mikhail Voloshin
Cecil J. Waddington
Thomas F. Walsh
Walter V. Weyhmann
John R. Winckler, emeritus
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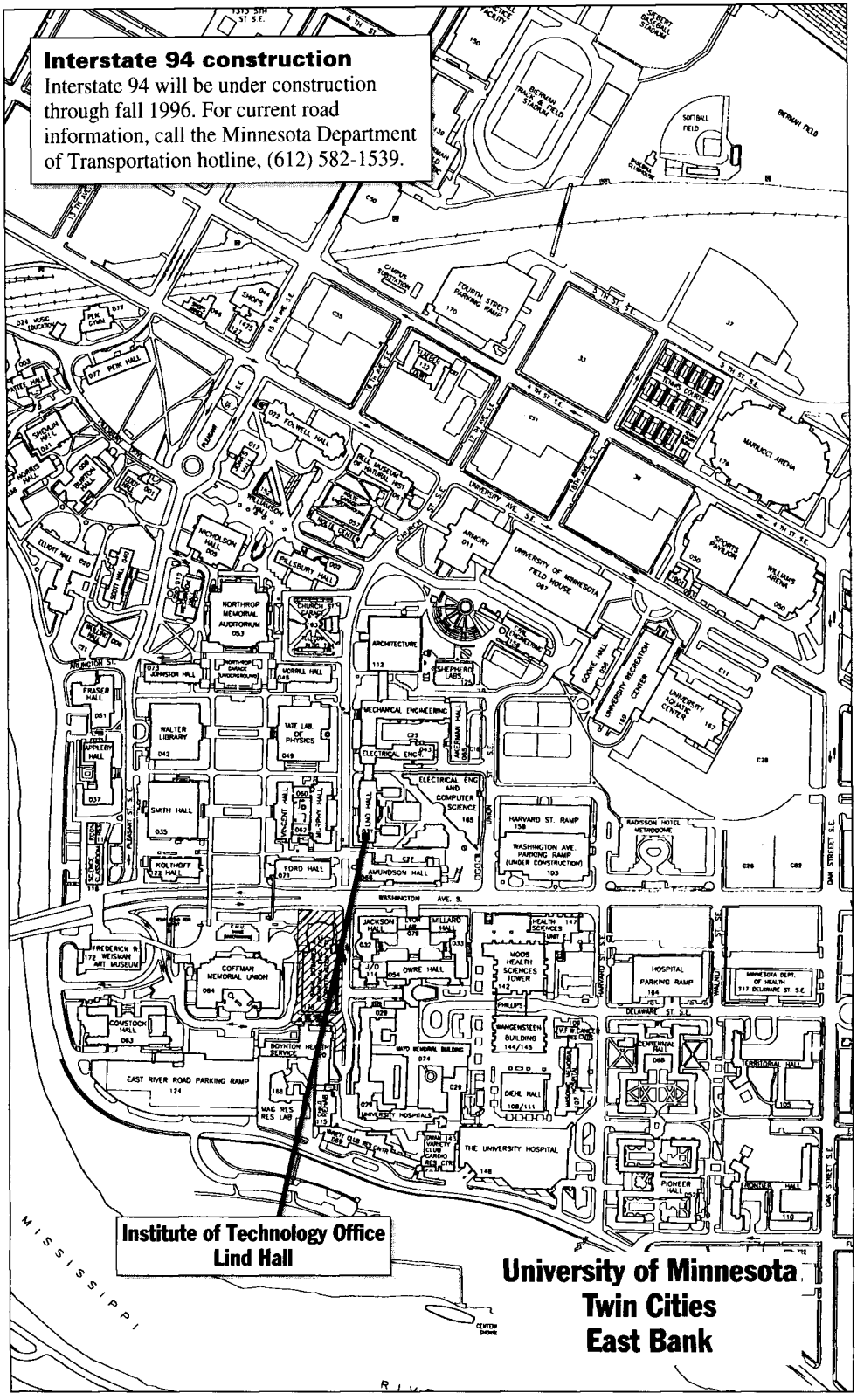
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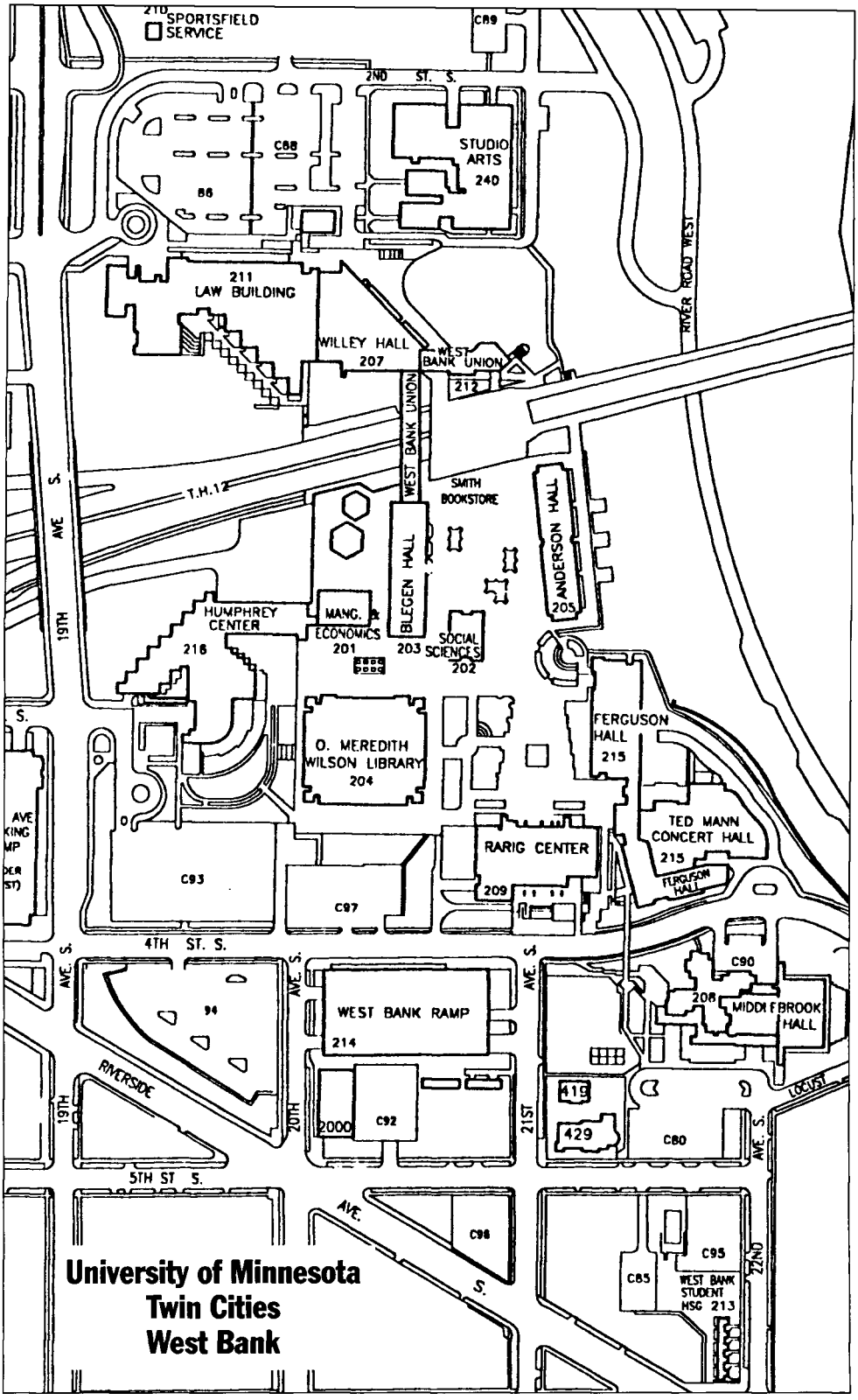

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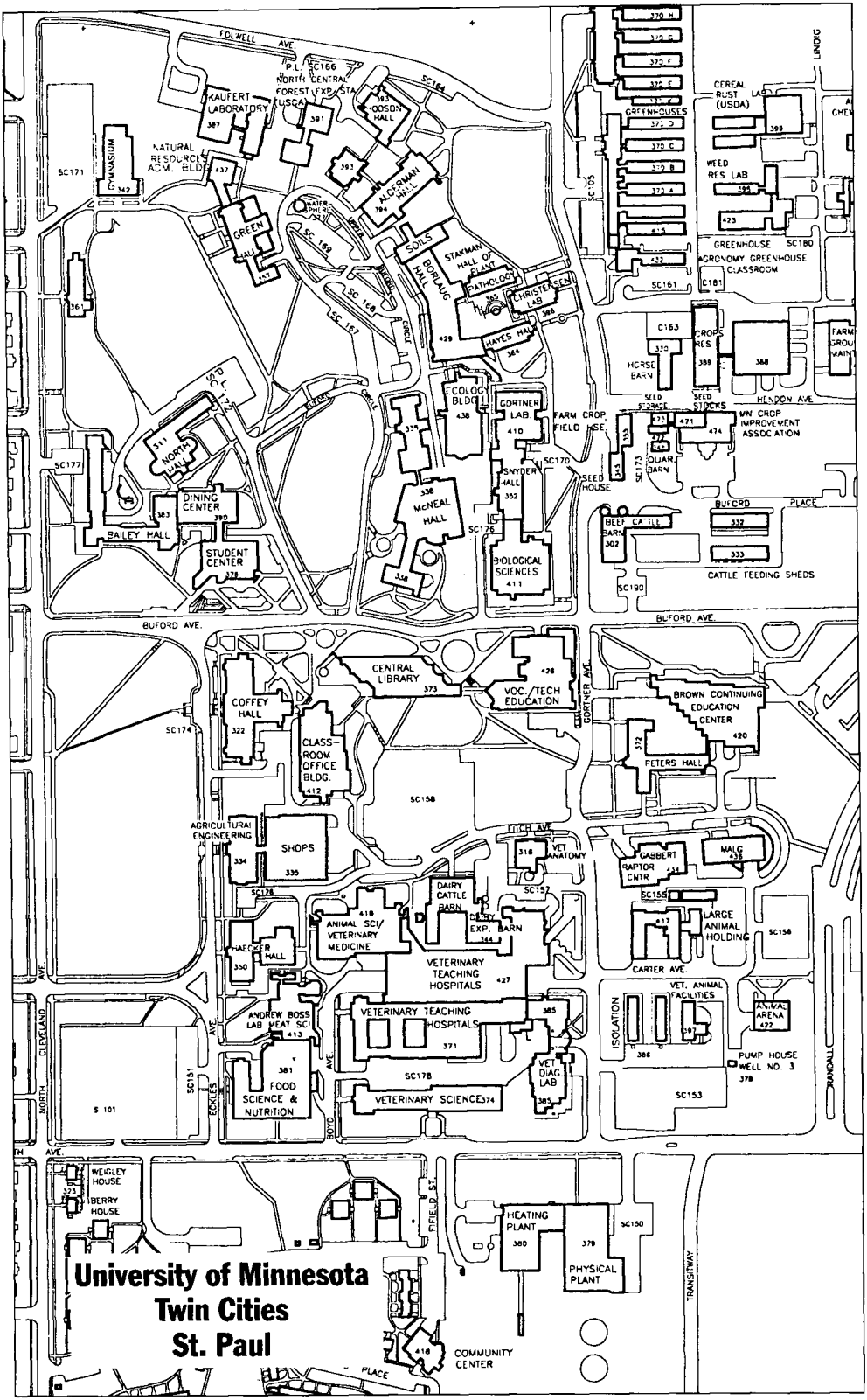
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Volume 98, Number 6
June 7, 1995

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Published by the University of Minnesota, Office of the Vice President for Student Affairs, Communications & Publications, 110 Williamson Hall, 231 Pillsbury Drive S.E., Minneapolis, MN 55455-0213; once in March; twice in April, May, June, July, August, and October; and three times in September. Second-class postage paid at Minneapolis, Minnesota. POSTMASTER: Send address changes to University of Minnesota, 110 Williamson Hall, 231 Pillsbury Drive S.E., Minneapolis, MN 55455-0213.

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