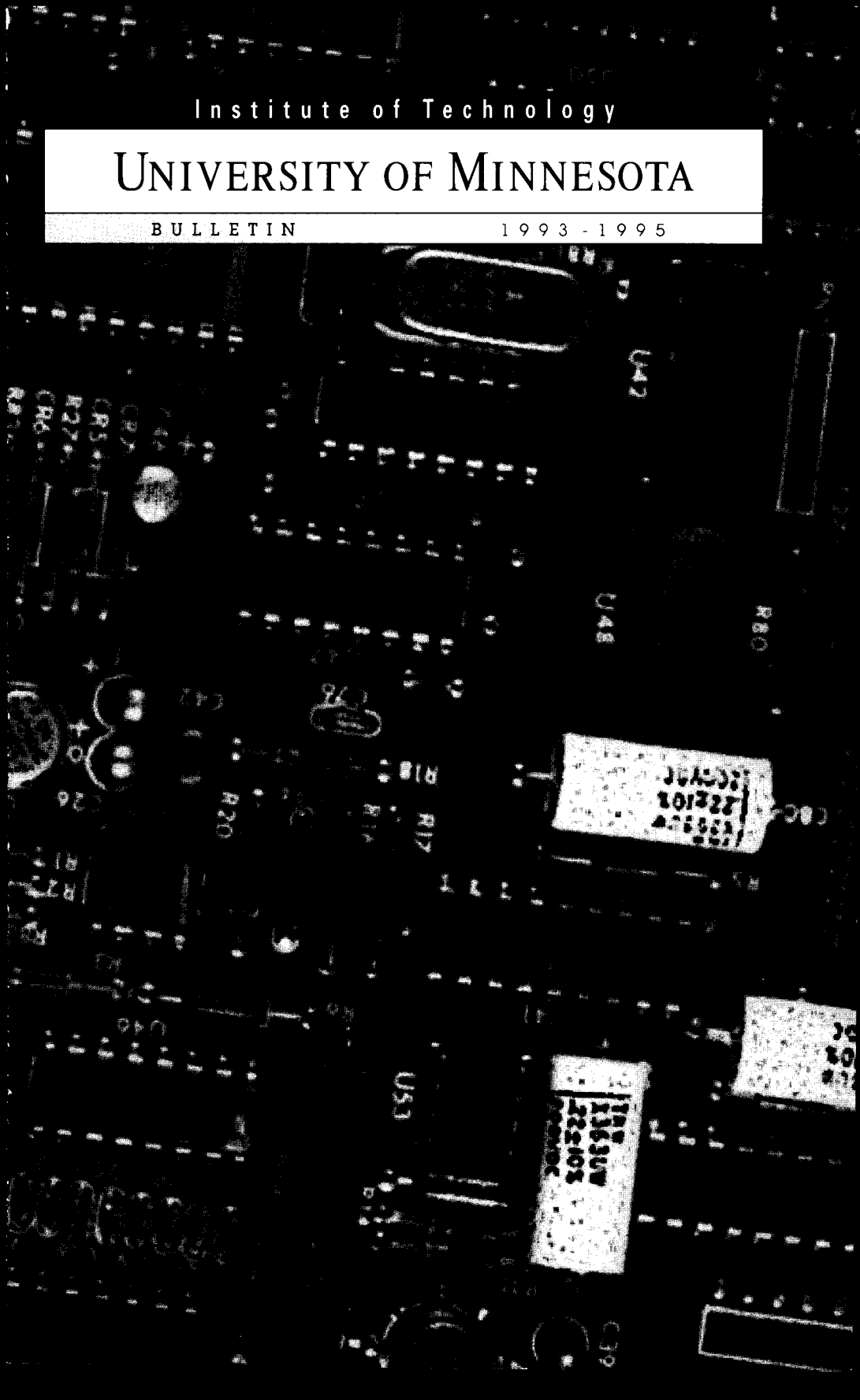
Institute of Technology

UNIVERSITY OF MINNESOTA

BULLETIN 1993-1995



Institute of Technology

General Information

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 Student 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.

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 150 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 contents of this bulletin and other University bulletins, publications, or announcements are subject to change without notice. University offices can provide current information about possible changes.

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, 420 S.C. 20000e; by the requirements of Title IX of the Education Amendments of 1972; by Sections 503 and 504 of the Rehabilitation Act of 1973; 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.

Postal Statement

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Programs and Services

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 the Institute's undergraduate programs provides a rigorous and stimulating education that is enhanced by close interaction with distinguished research faculty and access to the Institute's research facilities.

Sixteen degrees are offered:

bachelor of aerospace engineering and mechanics[1]
bachelor of agricultural engineering[1]
bachelor of science in astrophysics
bachelor of chemical engineering[1]
bachelor of chemistry
bachelor of civil engineering[1]
bachelor of 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 mathematics
bachelor of mechanical engineering[1]
bachelor of physics
bachelor of 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.

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.

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

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).

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 136 Lind Hall, 207 Church Street S.E., University of Minnesota, 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—The mission of Project Technology Power is to identify and remove barriers that discourage Africans, African Americans, American Indians, and Chicanos/Latinos from pursuing careers in engineering or science by providing technical, academic, and support programs at the pre-college and college levels. At the pre-college level, Project Technology Power sponsors academic enrichment programs for eighth- through tenth-grade students in Minneapolis and St. Paul. IT students, teachers, and industry representatives participate in the programs. At the college level, Project Technology Power offers academic and career counseling, merit scholarships, tutoring, practice interviews, and 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.

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). If necessary, you will be referred for a second interview to the IT Student Affairs Office, 105 Lind Hall, 207 Church Street S.E. (612/624-8504). 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. About one-third of the freshman class is admitted through individual review. 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 19 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. Have a combined high school rank percentile (HSR) and ACT or SAT score at or above the minimum levels shown in the table below. If you do not know your HSR, see your high school counselor.

Note: See page 11 for nonresident admission.

Test Score/High School Rank Thresholds for Automatic Admission to IT

If your ACT composite score is...	*or your SAT score is...*	*then your HSR percentile should be at least...*
30-36	1150+	70
29	1130-1149	72
28	1110-1129	74
27	1090-1109	76
26	1070-1089	78
25	1050-1069	80
24	1030-1049	82
23	1010-1029	84
22	990-1009	86
21	970-989	88
20	950-969	90

If your HSR percentile or your ACT or SAT score is below the minimums indicated on this table, your application will be considered through the Office of Admissions' individual review process. If your ACT math score is less than 26 or your SAT math score is less than 1070, your application will also be individually reviewed.

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, Agriculture, 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.

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 Unclassified" 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, over two hundred 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 unclassified 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.)

Credit Awards—High school students may be awarded college credit based on their participation in one of several programs:

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

Area/Test	Score	Awards
Art History	4	4 cr ArtH 1002 (Introductory)
	5	4 cr ArtH 1002 and 4 cr ArtH 1999
Biology	4,5	4 cr Biol 1008 (Introductory) and 5 cr Biol 1009 (General)
Chemistry	4,5	8 cr Chem 1051-1052 (General)
Classics		
Catullus	3-5	5 cr Lat 3105 (Catullus and Ovid)
Virgil	3-5	5 cr Lat 3106 (Virgil)
Computer Science A	4	4 cr CSci 3001 (Perspectives on Computers in Society)
	5	4 cr CSci 3001 (Perspectives on Computers in Society)
	4 cr	CSci 3102 (Intro to PASCAL)
Computer Science AB	3	4 cr CSci 3001 (Perspectives on Computers in Society
	4	4 cr CSci 3001 (Perspectives on Computers in Society 4 cr CSci 3102 (Intro to Programming)
	5	4 cr CSci 3001 (Perspectives on Computers in Society 4 cr CSci 3102 (Intro to Programming) 4 cr CSci 3121 (Fundamentals of Algorithms I)
English Language and Composition	3	Exemption from Comp 1011
	4,5	5 cr Comp 1011
Literature and Composition	3	Exemption from Comp 1011
	4,5	5 cr Comp 1011 and 4 cr Engl 1999 (miscellaneous credit)
French Literature	3-5	5 cr Fren 3099
Government		
American	4-5	5 cr Pol 1001
Comparative	4-5	4 cr Pol 1054
History		
American or European	4-5	8 cr Hist 1999
Math		
CalculusAB	4	4 cr Math 1251 (Calculus I)
	5	8 cr Math 1251-1252 (Calculus I-II)
CalculusBC	3	4 cr Math 1251 (Calculus I)
	4	8 cr Math 1251-1252 (Calculus I-II)
	5	12 cr Math 1251-1252, 3262 (Calculus I-II-III)
Physics C	4,5	8 cr Phys 1251-1252 (General)

Credit may also be awarded in political science and Spanish literature.

The College Level Examination Program (CLEP) is also sponsored by the College Entrance Examination Board. Minimum scores of 568 in the social sciences and 564 in humanities will cause 8 credits to be awarded per examination. No credit is awarded for the English, natural sciences, and math examinations. CLEP also offers subject examinations for credit. Information about further credit award may be obtained from 105 Lind Hall.

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

Area/Test		Score	Awards
Art/Design	(higher level)	5-7	4 cr Arts 1401 and 4 cr ArtS 1xxx
	(sublevel)	6-7	4 cr ArtS 1401 (Introductory)
Biology	(higher level)	5-7	4 cr Biol 1008 (Introductory) and 5 cr Biol 1009 (General)
	(sublevel)	6-7	5 cr Biol 1009 (General)
Chemistry	(higher level)	4-7	8 cr Chem 1051-1052 (General)
Comp Sci	(higher level)	5-7	8 cr CSci 3101 and 3121 *or* CSci 3102 and 3121
		4	4 cr CSci 3101 (FORTRAN) *or* 4 cr CSci 3102 (PASCAL)
	(sublevel)	5-7	2 cr CSci 1999
Economics	(higher level)	5-7	8 cr Econ 1101 and 1102 (Micro and Macro)
Geography	(higher level)	5-7	10 cr Geog 1301 (Human) and 1401 (Physical)
History	(higher level)	5-7	8 cr Hist 1999
Lang A—English	(higher level)	6-7	4 cr 3xxx-level English
Math	(higher level)	5-7	8 cr Math 1251-1252 (Calculus I-II)
		4	4 cr Math 1251 (Calculus I)
Music	(higher level)	5-7	6 cr Music 1999 (Music History) and 9 cr Music 1999 (Music Theory)
Physics	(higher level)	4-7	12 cr Phys 1251-1252-1253 (General Physics)
Psychology	(higher level)	4-7	5 cr Psych 1001 (Introductory)
Social Anth	(higher level)	6-7	5 cr Anth 1102 (Introductory)

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 private colleges. These programs are designed to 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, 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 10.

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 Student Financial Aid, 210 Fraser Hall, University of Minnesota, 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 $1,000 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.

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.

Undergraduate Teaching Assistants—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-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.

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, 16 Johnston Hall (612/624-4037, voice or TDD).

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. 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 grade point average.

S-N Grading Option—An IT student can elect the S-N grading option for any course offered on an S-N basis except those specifically designated by the student's major department to be taken on an A-F basis 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 on S-N grading 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 on S-N grading.

No more than 25% 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

Upper Division—The upper division corresponds to the junior and senior year. Transfer students are usually admitted directly into the upper division of their major field upon admission to IT.

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.*

[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.*

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.

ROTC Courses—Grades received in all ROTC courses will be entered on the student's transcript and will be counted in the GPA calculation. ROTC credits may be used to satisfy liberal education distribution requirements for those courses that have been certified as suitable for Group C (The Individual and Society) by the appropriate academic department of the University.

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

Students who graduate from IT 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 academic performance places them in the top 10% of their respective class qualify for the Dean's List. Students must complete at least 12 credits on A-F grading 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, and pay the graduation fee approximately 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. Further appeals go to college-level and University-level committees. 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.

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 at the University in the spring of every year and may be taken by students in their senior year. Further information and application forms may be obtained from 50 Lind Hall or from the Executive Secretary, Minnesota State Board of Architecture, Engineering, Land Surveying, and Landscape Architecture, 133 7th Street East, 3rd Floor, St. Paul, MN 55101-2333.

UNITE Instructional Television—Approximately 35 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 upon company policy.

Further information may be obtained from the Director, UNITE Instructional Television, 114 Lind Hall, 207 Church St. SE, Minneapolis, MN 55455 (612/624-2332).

Curricular Requirements

Curricular Requirements

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

Liberal Education Requirements

The University of Minnesota requires all students receiving a bachelor's degree to take liberal education courses. These courses are designed to help students become proficient in writing, to acquaint them with the means by which knowledge is acquired and communicated, to help them understand the ways in which engineers and scientists contribute to our knowledge of ourselves and our environment, to increase their historical and philosophical perspective on the nature of the individual and society, and to help them appreciate the value of the arts and literature in interpreting life and nature.

Breadth is assured by requiring students to take a minimum number of credits in each of the five areas described below. Two of the areas are met by mathematics and science courses required in the IT curriculum:

Group A: Language, Logic, Mathematics, and the Study of Argument, and

Group B: The Physical and Biological Universe

Students must take at least 36 credits in the following categories:

English Composition (8-9 credits)
Writing practice and *advanced composition* as specified by the student's major department. Most students complete writing practice by taking Composition 1011. The advanced composition course, usually taken in the junior or senior year, might be Composition 3031—Technical Writing for Engineers or Composition 3015—Writing About Science. Other 3xxx-level courses recommended by the major department are acceptable. Students who are exempt from the writing practice requirement can take 5 credits from Group C, Group D, or Group A (except for courses in mathematics, computer science, or statistics).

Group C: The Individual and Society (12-15 credits)

Group D: Literary and Artistic Expression (8-10 credits)

The remaining credits to complete 36 may be taken in Groups C, D, A (except for courses in mathematics, computer science, or statistics), or B (some courses). Group B courses may include courses in the biological sciences and ecology, unless they are specifically excluded by the student's major department. Courses in astronomy, chemistry, computer science, geology, mathematics, physics, business, accounting, and related areas may *not* be used to fulfill the liberal education requirements. Courses in air, military, or naval science may not be used unless they have been accredited for use in Group C or D by one of the departments in the College of Liberal Arts. A current list of such courses is available in 105 Lind Hall. Skills courses in a foreign language other than the student's native language may be used to complete the 36 credits.

Students in engineering programs must take at least 24 credits total in Groups C and D combined. Skills courses in a foreign language other than the student's native language may not be used to satisfy the Group C or D minimum credits respectively, but they may be used to satisfy the extra 4 credits required by the Accreditation Board for Engineering and Technology (ABET) to total 24 credits between the groups. Foreign language skills courses may also be used for the additional credits needed to total 36 liberal education credits. Majors in astrophysics, chemistry, and physics have additional liberal education requirements that are described under those majors in this section of the bulletin.

Study in depth is also a requirement. Students must take two advanced courses in Group C or D. That means they must either be at the 3xxx or 5xxx level or have a prerequisite.

Music performance courses must be accompanied by theory or history of music to be considered for Group D credit.

The All-University Council on Liberal Education expects to implement new liberal education requirements during the 1994-95 academic year. A complete description of the changes will be available for review in 105 Lind Hall beginning fall quarter 1993.

Selecting Liberal Education Courses

The size and breadth of the University of Minnesota provides an opportunity for taking many different courses to satisfy the liberal education requirements. Selected well, these courses can enhance your subsequent professional activities by showing you areas of knowledge, ways of thinking, and cultural perspectives that you would not otherwise encounter. They can also help you discover and explore your own interests and concerns. You will find the courses more interesting and more rewarding if you pay some attention to selecting them wisely. A booklet to help you, *Liberal Education Courses for Students in the Institute of Technology,* is available in 105 Lind Hall and department offices.

You are strongly encouraged to select your courses with some integrating purpose or theme in mind. For example, you might select as a theme "the art of film." Although courses

such as Introduction to Film Study, Cinema and Ideology, Scandinavian Film, The Cinema of India or The Japanese Cinema are all in Group D, they would teach you about other cultures as well as cinematic literature.

A theme such as "American minority cultures" would allow you to combine Group C courses like Introduction to Afro-American Studies, Introduction to American Indian Studies, The Chicano in Contemporary Society or Asians in America: An Ethnic Perspective with Group D courses such as Afro-American Music Through the 1920s, American Indian Literature, Chicano Music and Art, or Women and the Arts.

A theme like "China and Japan" would allow you to select from Group C courses like Introduction to East Asia, Religions of East Asia, Geography of East Asia and Modern Japanese Society, along with such Group D courses as Introduction to Far Eastern Art, Twentieth Century Chinese Literature in English, Japanese Cinema, and Music in East Asia.

A cluster centered on "science, technology and ethics" could include Technology and Western Civilization, Introduction to Ethics, Science and the Humanities, and Revolutions in Science and the Arts.

You are encouraged to look at the examples of course clusters shown in *Liberal Education Courses for Students in the Institute of Technology*. You might select one of these themes or develop your own. The booklet lists a large number of courses that are acceptable for Group C or D credit for IT students. By selecting from these courses, you can develop a theme.

First-Year Core

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

Note that students majoring in chemistry, chemical engineering, or materials science begin chemistry courses their freshman year. Also, in fulfilling the mathematics requirements, some students have the option of taking Math 1251-1252-1261 or Math 1551H-1552H-1553H. Alternative physics sequences are Phys 1251-1252-1253-1254 or Physics 1451H-1452H-1453H-1454H (Honors Physics); these sequences may be started concurrently with Math 1251 (Calculus I) or the equivalent.

CORE A

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

	Credits		
	f	w	s
Math 1251-1252-1261—Calculus I-II-Linear and Non-linear Multivariable Analysis I	4	4	4
Comp 1011—Writing Practice I	5	...	...
Phys 1251-1252—General Physics	...	4	4
Elective in computer science, introduction to engineering, or nontechnical area	4-5	4	4-5
	13-14	13	13-14

CORE B

Chemical Engineering, Chemistry, Materials Science

	Credits		
	f	w	s
Math 1251-1252-1261—Calculus I-II-Linear and Non-linear Multivariable Analysis I	4	4	4
Chem 1051-1052—Chemical Principles I-II	4	4	...
Comp 1011—Writing Practice I	5	...	...
Phys 1251-1252—General Physics	...	4	4
Nontechnical elective	...	4	4
	13	16	16

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 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.

Lower Division

	Credits
Comp 1011—Writing Practice I	5
Liberal education electives	15
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
	97

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 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

Agricultural engineering is the application of engineering principles to biological and environmental systems involving soil, water, and air in the production and processing of plant, animal, food, and related biological materials. Agricultural engineers 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.

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. Agricultural engineers apply biological, environmental, agricultural, 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. 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. The program provides students with a fundamental background for continued professional growth and prepares them to contribute to an ever-changing society.

The curriculum centers around environmental and natural resource management. Students, with the assistance of an adviser, plan a curriculum tailored to their individual interests. 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.

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
Biological science electives (4 cr at 3xxx or 5xxx level; including agricultural science courses with significant biological content)	8
AgEn 1060—Agricultural Engineering Orientation	1
ME 1025—Engineering Graphics	4
AEM 1015—Statics	4
AgEn 3031—Computations in Agricultural Engineering	4
AEM 3016—Deformable Body Mechanics	4
CE 3400—Fluid Mechanics	4
CSci 3101, CSci 3102 or AgET 3030—Computer Programming	4
Liberal education electives	16
	97-98

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
AEM 3036—Dynamics	4
ME 3301-5342—Thermodynamics, Heat Transfer	8
ME 3900—Introduction to Engineering Statistics	4
Biological science elective (at 3xxx or 5xxx level; including agricultural science courses with significant biological content)	4
AgEn 3052—Engineering Principles of Soil-Water-Plant Systems	4
AgEn 5891-5892—Senior Design I-II	5
AgEn 5540—Watershed Engineering	4
Agricultural engineering electives Must include:	
a) Two courses from:	8
AgEn 5070—Automatic Controls and Instrumentation	
AgEn 5072—Finite Element Methods	
AgEn 5074—Microcomputer Interfacing	

b) One course from: 4
AgEn 5550—Water Management Engineering
AgEn 5910—Agricultural Waste Management Engineering
c) Agricultural engineering elective 4
Engineering electives to satisfy ABET requirements of 48 engineering science credits and 24 engineering design credits 12
Liberal education electives 11-12
Electives to consider student interest and to meet graduation requirements of 190 credits 11

92-93

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.

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

(Based on 180 credits)

	Credits
Liberal education	36
Of these 36 credits, at least three courses (12-15 credits) must be in Group C (The Individual and Society) and at least two courses (8-10 credits) must be in Group D (Literary and Artistic Expression). The remaining courses may be in any of the above categories. Consult the general Institute of Technology requirements.	
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 3012, 3515—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 3201—Thermodynamics
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

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 (200 credits for students starting college before fall 1991). Students must satisfy the IT minimum liberal education requirements (a total of 36 credits including at least 3 in biological science) as part of a pre-chemical engineering program and complete a coherent degree program of science and technical courses, which includes 48 credits of engineering science and 24 credits of engineering design. Both predegree and degree curricula are outlined on the following pages.

The student, together with her or his adviser, plans the degree program in stages: a one-year plan is submitted every year, and, ordinarily, a complete four-year program is submitted for certification by the department before the beginning of the fourth year. By selecting appropriate technical electives and, in certain cases, substituting courses with approval of the adviser and department, students can emphasize various special interest areas in their upper division curriculum. Sample programs that illustrate these possibilities are available from the 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, 151 Amundson Hall, University of Minnesota, 421 Washington Avenue S.E., Minneapolis, MN 55455.

Lower Division

	Credits		
First Year	f	w	s
Comp 1011—Writing Practice I	5	...	...
Math 1251-1252-1261	4	4	4
Chem 1051-1052—Chemical Principles I-II	4	4	...
Phys 1251-1252—General Physics, Laboratory	...	4	4
Biology 1009	...	...	5
Liberal education electives	4	4	4
	17	16	17

	Credits		
Second Year	f	w	s
Chem 3301, 3302, 3305, 3306, 5126—Introductory Organic Chemistry I-II with Laboratories and Modern Analytical Chemistry	6	6	4
Phys 1253	4	...	...
Math 3251, 3261, 3352	4	4	4
ChEn 3001, 5001—Computation	...	2	4
Liberal education electives	4	4	4
	18	16	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.

Also note that the required lower division biological science elective fulfills both chemical engineering and liberal education requirements.

Upper Division

	Credits		
Third Year	f	w	s
ChEn 5101, 5102, 5103—Principles: Stoichiometry and 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 laboratory emphasis elective	...	4	1
	16	16	13

	Credits		
Fourth Year	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 laboratory 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 to understand the world around us. Chemistry deals with matter—what substances are made of, their properties, and how they are transformed into new substances. Chemistry is central to research in areas of great importance to society such as super conductivity, biotechnology, high tech polymers, drugs, cheap and clean energy, removing and preventing environmental pollution, and new materials for electronics and catalysis. As a chemist you could be the first to prepare a new compound with an important property such as high heat stability,

to unravel the structure of a complex molecule such as a part of a cancer cell, or to synthesize a more effective medication of high blood pressure that has no side effects.

Chemistry provides a broad range of opportunities in many specialized fields from biotechnology to polymer chemistry, offers a variety of work from collecting field samples to writing for a journal; provides varying levels of responsibility such as manager, lab supervisor, researcher, teacher, or technician; and offers employment opportunities in government, industry, schools and private organizations. Chemistry also offers professional status, advancement opportunities, good work conditions, and growth potential.

A chemist is a scientist. Most chemists work in modern laboratories equipped with sophisticated instruments and powerful computers. Chemists can synthesize new materials and learn to use known materials for new purposes. They can deal with questions such as "How old is the Earth?" and "What is happening to the ozone layer?". Other chemists, such as managers or information specialists, do not perform experiments in laboratories.

A chemist is a problem solver. They often work in teams with other scientists and engineers. Finding solutions to problems sometimes requires the expertise of many disciplines. Chemists will provide the primary force for solving the world's enviromental and energy problems.

A chemist is an important part of the work force and the economy. There are some 185,000 chemists in the work force. They produce a great variety of consumer products, from plastics to gasoline, and make special materials such as a rocket fuel and new semiconductors for microchip technology. Chemical and related industries produce a substantial amount of our exports.

A chemist is a college or graduate school degree holder. About 40% of working chemists have bachelor's degrees in chemistry or related fields. Some 18% have master's degrees, and 35% have doctorates. About 60% of all chemists find employment in industry, 20% go into education, 10% work for the government, and 10% go elsewhere. Today there are wonderful employment opportunities for chemists with excellent starting salaries and benefits.

After graduating with a bachelor's degree, a chemistry major may go on to graduate school to receive an advanced degree (M.S., Ph.D., or M.D.), they may begin their careers by working in the laboratory, or they may seek a degree or certificate in another complimentary area such as education, language, business, or law.

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

- A minimum of 180 credits for graduation. All required courses including the foreign language but excluding freshman writing practice must be taken A-F.
- Freshman writing practice (or exemption) and advanced writing course (9 credits).
- One year of any foreign language (15 credits) to acquire ability to read the literature of the field in that language. A computer language may not be substituted for the foreign language but is recommended in addition to it.
- One year of calculus-based physics (12 credits).
- Six quarters (24 credits) of mathematics.
- 59 credits of chemistry.
- Minimum liberal education requirements (36 credits). 9 credits of English, if taken, and 8 credits of a foreign language may be included in this total.
- Electives (35-40 credits), chosen by the student in consultation with her or his adviser, but otherwise without restriction.
- Grade of C or better in all technical courses.

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

A special course program recommended for premed chemistry majors. This program includes a number of substitutions, the appropriate biology and biochemistry courses, and a reduction in some of the normally required chemistry courses. It is also possible to obtain degrees in chemistry and chemical engineering in the same time normally required for one of the degrees. This double major option requires careful course planning and should be discussed as early as possible with a chemistry adviser. All chemistry majors are carefully 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 four-year degree plan must be certified by the department early during the last year.

Electives—The required chemistry, mathematics, and physics courses are presented in the recommended schedule below. The English and language courses are included in the electives listing in the schedule. In addition to advanced courses in chemistry, students are encouraged to do senior research projects: 3970 or 5970—Directed Study. Other areas especially recommended for elective work are biochemistry, biology, chemical engineering, computer science, mathematics, medicinal chemistry, physics, and physiological chemistry.

By selecting appropriate electives and making approved course substitutions it is possible for a student to put together a program with emphasis in special interest areas. Chemistry advisers can be helpful in putting together such special programs.

Special Opportunities—The chemistry department offers opportunities for undergraduate research with many of its outstanding 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.

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 course 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).

Lower Division

	Credits		
First Year	f	w	s
Chem 1051-1052—Chemical Principles I-II	4	4	...
Math 1251-1252-1261—Differential Calculus, Integral Calculus, Algebra and Geometry of Euclidean Space	4	4	4
Phys 1251-1252—General Physics Lecture and Laboratory I-II	...	4	4
Electives including Comp 1011	8	4	8
	16	16	16

	Credits		
Second Year	f	w	s
Chem 3301, 3302, 3303—Elementary Organic Chemistry I-III	4	4	4
Chem 3305, 3306, 3336—Elementary Organic Chemistry Laboratory I-II, Introductory Organic Chemistry Laboratory III	2	2	2
Math 3251-3252-3261—Vector Differential Calculus, Multivariable Integral Calculus, Differential Equations with Linear Algebra	4	4	4
Physics 1253—General Physics Lecture and Laboratory III	4	...	...
Electives	2	6	6
	16	16	16

Upper Division

	Credits		
Third Year	f	w	s
Chem 5534—Chemical Thermodynamics	4	...	...
Chem 5535—Statistical Mechanics and Reaction Kinetics	...	4	...
Chem 5533—Quantum Chemistry[1]	...	...	4
Chem 5731, 5732—Inorganic Chemistry I-II	3	3	...
Chem 5130-5131—Analytical Chemistry Lecture and Laboratory	...	...	5
Electives	9	9	7
	16	16	16

	Credits		
Fourth Year	f	w	s
Chem 5133—Chemical Instrumentation and Analysis	3	...	...
Chem 5140—Chemical Instrumentation and Analysis Laboratory	...	3	...
Chem 5540—Physical Chemistry Laboratory	3	...	...
Chem 5740—Inorganic Chemistry Laboratory	...	...	3
Comp 3015—Writing About Science	...	4	...
Electives	10	9	13
	16	16	16

[1]A *student who wishes to complete more of the required chemistry courses in the first two years may take 3301—Elementary Organic Chemistry in the third quarter of their first year and 5533—Quantum Chemistry in the third quarter of their second year.*

Civil Engineering

(Department of Civil and Mineral Engineering)

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

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

The bachelor of civil engineering (B.C.E.) degree program requires a minimum of 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 and Mineral Engineering, is the site of water resources research.

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

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

Civil 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 4 credits. For more information, contact the Director of the Civil Engineering Intern Program, Department of Civil and Mineral Engineering, 122 Civil and Mineral Engineering, University of Minnesota, 500 Pillsbury Drive S.E., University of Minnesota, 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.

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 142 Civil and Mineral 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
CE 1001—Civil Engineering Orientation	1
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 or 3102—FORTRAN or PASCAL Programming	4
CE 3400—Fluid Mechanics	4
Liberal education electives	16
	95

Upper Division

	Credits
CE 3100—Introduction to Surveying and Mapping	4
CE 3200—Introduction to Transportation Engineering	4
CE 3300—Elements of Soil Mechanics	4
CE 3301—Soil Mechanics Laboratory	1
CE 5002—Engineering Economics	2
One course from the following list:	4
CE 5102—Site and Route Engineering	
CE 5201—Highway Traffic Characteristics and Operations	
CE 5210—Introduction to Transportation Systems Analysis	
CE 5304—Design of Highway and Airport Pavements	
CE 5301—Foundation Engineering	4
CE 5401—Water Resources Engineering	4
CE 5405—Hydrology and Hydrologic Design	4
Two courses from the following list	8
CE 5500—Analysis and Design of Water Supply Systems	
CE 5501—Analysis and Design of Wastewater Systems	
CE 5506—Environmental Water Chemistry	
CE 5603—Introduction to Construction Materials	4
CE 5600—Linear Structures Systems	4
CE 5610—Design of MetalStructures	4
CE 5611—Design of Reinforced Concrete Structures	4
Technical Electives[2]	24
Comp 3031—Technical Writing for Engineers	4
Liberal education electives	11
Free electives	3
	97

[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 engineering science and technical electives in 142 Civil and Mineral Engineering.

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.

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 degree of bachelor of computer science (B.Comp.Sci.). 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 on A-F grading 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	
Elective courses that form a coherent program in computer science or application areas; for example, artificial intelligence, computer design and engineering, health sciences,	

management information systems, mathematics of computation, software design, 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 32

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

Electrical Engineering

The electrical engineering program seeks to prepare its graduates for careers in electrical engineering and to provide a foundation for continued professional development.

The electrical engineering curriculum offers students an opportunity to concentrate in any of a number of specialized areas, including control and communications systems, bioengineering, computer engineering, digital circuits and systems, electric energy conversion and power systems, power electronics, microelectronic devices and circuit design, and physical electronics. 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 3121—Survey of Data Structures and Algorithms	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
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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

Geological Engineering

(Department of Civil and Mineral 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 and Mineral Engineering, 234 Civil and Mineral Engineering (612/625-3811).

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 192 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 requiremets, 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 142 Civil and Mineral 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 and Mineral 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

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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 3301—Soil Mechanics Laboratory	1
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]	
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—Foundation Engineering	4
GeoE 5218—Design of Underground Excavations in Rock	4
GeoE 5302—Applied Rock Mechanics	4
GeoE 5437—Computer Applications II	4
	98
TOTAL	**192**

[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 183 credits is required for completion of the B.S.Geol. and 187 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 Geol 3201)	
Chem 1051-1052 (should be taken as early as possible; Chem 1051 is a prerequisite for Geol 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), Geol 3301—Geochemical Principles (4 cr), Geo 3401—Mineralogy (4 cr)	
Spring: Geo 3301—Geochemical Principles	
Junior Year	
Fall: Geo 3402—Petrology (4 cr)	
Spring: Geo 5651—Sedimentology (4 cr), Geo 5201—Structural Geology (4 cr)	
Summer After Junior Year	
Geo 5111—Field Camp (9 cr)	
	69

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	
Fall: Geo 5101—Geochronology and Stratigraphy (4 cr)	
Winter: Geo 5631—Earth-System Science (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-level geology course may also be used.	
Total	16
Free electives	18
Total credits for geology major	183

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-level geology course may also be used.	
Total	16
Free electives	10
Total credits for geophysics major	187

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 more information, see the co-op program description included 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

[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.

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.

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 laboratory studies.

Degree Requirements—To receive a bachelor of materials science and engineering degree, students must complete 192 credits of

coursework with an approved program (200 credits for students starting college before fall 1991). These credits include a minimum of 36 liberal education credits, approximately 64 credits in basic sciences, and approximately 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, 151 Amundson Hall, University of Minnesota, 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

	Credits		
First Year	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

	Credits		
Second Year	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, ChEn 5001, Computational Methods	...	2	4
AEM 1015—Statics	4	...	...
AEM 3016—Deformable Body Mechanics	...	4	...
Liberal education electives	4	...	4
	16	14	16

Upper Division

	Credits		
Third Year	f	w	s
MatS 5011-5012-5013—Introduction to Science of Materials, Physical Metallurgy, Electronic Properties	4	4	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	4
Total	16	16	16

	Credits		
Fourth Year	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 mathematics (B.Math.) 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.

In addition to the prescribed courses listed below, a student must complete the minimum liberal education requirements of the Institute of Technology, including an upper division technical writing course. Comp 3015—Writing About Science, is the appropriate upper division composition course for most Math majors. Other composition courses may be taken with adviser approval.

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—One-Variable Differential Calculus
1252—One-Variable Integral Calculus
1261—Algebra and Geometry of Euclidean Space
3251—Multivariable Differential Calculus
3252—Multivariable Integral Calculus
3261—Differential Equations with Linear Algebra
3262—Sequences, Series, and Approximation

These seven courses do not have to be taken in the order listed and some can be taken concurrently.

There is a parallel sequence of honors courses: 1551H-1552H-1553H-3551H-3552H-3541H. These courses must be taken in the order listed and in consecutive quarters. The honors sequence may be entered at the beginning (1551H) or at the level of 1553H, which corresponds roughly to 1261. Screening for admission to 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 (3102—PASCAL Programming is recommended) and complete a 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 will usually still start with 1261, but often will exempt 3262. Transfer students presenting a year-long, complete calculus-based physics course may be exempted from further physics, provided the course covered the subject matter of the University's physics sequence. 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), methods of applied mathematics (5457-5458-5459), numerical analysis (5473-5474-5475 or CSci 5301-5302-5304-5305-5306), ordinary differential equations (5521-5522-5523), 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 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. (See Special Programs.)

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

The mechanical engineering program consists of a minimum of 27 liberal education elective credits, a coherent technical elective program of approximately 24 credits, and other free elective credits. Thus the student has the responsibility of selecting approximately 56 credits of coursework. 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, mechanical-electrical engineering emphasis, and packaging engineering.

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.

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.

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 biology, physiology, chemistry, fluid flow, and similar areas with related engineering courses to prepare for work or graduate study in bioengineering. Students preparing for work in bioengineering may also plan their studies to meet medical school entrance requirements.

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).

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.

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, Vector 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 FORTRAN Programming, 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 (approximately) 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.

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

(approximately 16 credits per quarter)

	Credits		
First Year	f	w	s
Phys 1251-1252-1253	4	4	4
Math 1251-1252-1261	4	4	4
Chemical Principles I-II (if desired)			
Writing Practice I (if required)			
Foreign language (if required)			
Liberal education electives	4-8	4-8	4-8
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	4-6	4-6
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	0-4	0-4	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	8

Technical Electives—The curriculum includes a minimum of 33 credits of technical electives. Mathematics, chemistry, engineering, biophysics, and other areas may be of interest. 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 5202—Introduction to Thermal and Statistical Physics
- Phys 5031-5032—Topics in Mathematical 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 statistics (B.Stat.) 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 3012-3091	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

Course Descriptions

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

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

† All courses preceding the dagger 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 allowed (or required) in the course listed after the paragraph mark.

Registration Override Permit, completed and signed by the instructor, is required for registration.

Δ Registration Override Permit, completed and signed by the department 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. In prerequisite listings, comma means "and" (e.g., "prereq 1101, 1102 or 1103" means the prerequisites are 1101 and either 1102 or 1103).

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 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 laboratory in database searching.

Aerospace Engineering and Mechanics (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.

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.

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.

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.

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.

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.

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.

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.

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, response of free and forced systems, elementary concepts in feedback control, frequency response.

5001ss. 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).

5002ss. 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.

5200f. KINEMATICS AND DYNAMICS OF FLUID FLOW. (4 cr; prereq upper division 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.

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.

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

5206w. AERODYNAMICS OF LIFTING SURFACES. (4 cr; prereq 5200, CSci 3101 or 3104)
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.

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.

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.

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.

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.

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.

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.

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.

5322s. AEROSPACE VEHICLE CONTROL. (4 cr; prereq upper div IT or grad student, 5319 or equiv, 5321 or equiv or #)
Applies the classical and multivariable methods of control system analysis and design to aerospace vehicle control. Includes flight control of airplanes, helicopters, and spacecraft and trajectory control of aircraft. Design projects required.

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.

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

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.

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.

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.

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.

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.

5440w. DYNAMICS OF SYSTEMS AND STRUCTURES. (4 cr; prereq IT or grad student, 5438)
Application of Lagrangian methods to multi-degree of freedom systems; vibration of strings, rods, shafts, and beams; frequency and time domain analysis of multi-degree of freedom mechanical systems. Introduction to finite elements in structural dynamics.

5515w. AEROSPACE STRUCTURES I. (4 cr; prereq IT student, 3016)
Elastic analysis of components important to aerospace structures. Finite element methods. Elastic limit and post-elastic behavior of trusses. Matrix methods for isotropic metals and composite materials in plane stress. Design and analysis of thin-walled and semi-monocoque structural members in bending and torsion. Energy and Castigliano methods for statically indeterminate structures.

5516s. AEROSPACE STRUCTURES II. (4 cr; prereq IT student, 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.

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.

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.

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.

5630, 5631, 5632f,w,s. AEROMECHANICS LABORATORY I-III. (4 cr per qtr; prereq upper div IT student, 3016, 3036, 5200)
Designing experiments. Wind tunnel experiments including lift and drag measurement, flow visualization, pressure and velocity measurement techniques. Vibrations and properties of materials and structures. Control of systems.

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.

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, laboratory experience in sound and noise measurements and noise control techniques.

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.

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.

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.

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).

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

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

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

8201, 8202, 8203. FLUID MECHANICS I-III

8207. HYDRODYNAMIC STABILITY AND BIFURCATION I

8208. HYDRODYNAMIC STABILITY AND BIFURCATION II

8209. ROTATING FLUIDS

8216, 8217. THEORY OF TURBULENCE I-II

8219. COMPUTERS IN THE LABORATORY

8220. RHEOLOGICAL FLUID MECHANICS I

8221. RHEOLOGICAL FLUID MECHANICS II

8232. PHYSICAL GAS DYNAMICS

8240. PERTURBATION METHODS IN FLUID MECHANICS

8250. COMPUTATIONAL AERODYNAMICS

8260. NONLINEAR WAVES IN MECHANICS I

8410. ADVANCED DYNAMICS

8411. LINEAR SYSTEMS

8412. NONLINEAR SYSTEMS

8413. ADVANCED NONLINEAR SYSTEMS

8414. HAMILTONIAN SYSTEMS ON MANIFOLDS

8415. ADVANCED TOPICS IN DYNAMICAL SYSTEMS

8420. TRAJECTORY OPTIMIZATION TECHNIQUES

8421. MODERN CONTROL THEORY FOR AEROSPACE SYSTEMS

8422. ROBUST MULTIVARIABLE CONTROL DESIGN

8425. ADVANCED TOPICS IN AEROSPACE GUIDANCE AND CONTROL

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

8510. CONTINUUM MECHANICS I

8511, 8512. CONTINUUM MECHANICS II-III

8522. THEORY OF PLASTICITY

8540. THEORY OF VISCOELASTICITY

8570. FRACTURE MECHANICS

8585, 8586, 8587. ADVANCED TOPICS IN CONTINUUM MECHANICS

8588. THEORY OF LIQUID CRYSTALS

8589. MECHANICS OF CRYSTALLINE SOLIDS

8594. ELASTOSTATICS I

8595. ELASTOSTATICS II

8596. ELASTODYNAMICS

8601. FINITE ELEMENT METHODS IN COMPUTATIONAL MECHANICS

8602. FINITE ELEMENT METHODS IN COMPUTATIONAL FLUID MECHANICS

8777. THESIS CREDITS: MASTERS

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

8810, 8811, 8812. SELECTED TOPICS IN FLUID MECHANICS

8880. THESIS CREDITS: DOCTORAL

8888. PLAN B PROJECT

Agricultural Engineering (AgEn)

1060f,s. AGRICULTURAL ENGINEERING ORIENTATION. (1 cr; S-N only; 2 hrs per wk)
Introduction to agricultural engineering practice through lectures, readings, discussions, and presentations by practicing engineers. Discussion of safety, ethics, and professionalism in engineering. Identification of opportunities in the profession.

3031s. COMPUTATIONS IN AGRICULTURAL ENGINEERING. (4 cr; prereq IT student, computer programming, Math 3261 or ¶; 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.

3052f. ENGINEERING PRINCIPLES of SOIL-WATER-PLANT SYSTEMS. (4 cr; prereq IT student, some biology background, AEM 3016 or concurrent regis; 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.

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.

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.

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.

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.

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.

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.

5150s. BIOLOGICAL PROCESS ENGINEERING. (4 cr; prereq BioC 3031 or Biol 5001, #; 4 lect hrs per wk)
Reaction kinetics of hydrolysis of hemicellulose, cellulose, and starch to fermentable sugars. Fundamentals of fermentation and separation of alcohols, organic acids, insecticides, and biodegradable plastics.

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.

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, driveline design, power unit selection, and duty cycle analysis.

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.

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.

5560w. MECHANICS OF FLOW IN THE UNSATURATED ZONE. (4 cr; prereq upper div IT or grad IT or College of Agriculture 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.

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.

5751f. BIOCHEMICAL ENGINEERING I. (3 cr, §ChEn 5751; prereq AgEng 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.

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.

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.

5910w. AGRICULTURAL WASTE MANAGEMENT ENGINEERING. (4 cr; prereq upper div IT or grad IT major, 3052, Chem 1005, 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.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

8000. SUPERVISED TEACHING EXPERIENCE

8100. SEMINAR

8190, 8191, 8192. ADVANCED PROBLEMS AND RESEARCH

8500. HYDROLOGIC MODELING—SMALL WATERSHEDS

8700. MOISTURE AND HEAT TRANSFER

Astronomy (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.

1015. DESCRIPTIVE ASTRONOMY LABORATORY. (1 cr, §1025; prereq high school algebra; high school trigonometry recommended; 1 lab hr per wk)
Laboratory offered in conjunction with 1011. Only opportunity to observe with telescope. Occasional nighttime observing sessions required.

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.

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.

1025H. INTRODUCTION TO ASTRONOMY LABORATORY. (1 cr, §1015; prereq high school algebra, trigonometry, and physics or chemistry; 1 lab hr per wk)
Laboratory 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.

1031A,L. EXPLORING THE UNIVERSE. (4 cr; 3 lect hrs per wk [1 active learning session hr per wk for 1031A, 2 lab hrs per wk for 1031L])
The human place in the universe. Study of the Earth as a planet, other planets, the sun, stars, and galaxies. Background and fragility of life on Earth. Scale, origin, and history of the universe and our relationship to it.

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.

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

3051. 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.

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

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.

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 laboratory at scientific computer work station.

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.

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.

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.

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.

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.

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.

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.

5201s. METHODS OF EXPERIMENTAL ASTROPHYSICS. (4 cr: prereq 3051, Phys 3513; 2 lect, 6 lab hrs per wk)
Introduction to 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.

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.

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.

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.

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.

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. Primarily intended for senior astrophysics majors.

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*)

8200.* SEMINAR: ASTROPHYSICS AND SPACE PHYSICS

8481, 8482, 8483.*TOPICS IN ASTROPHYSICS

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)

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.

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.

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)
Introduction to analysis of representative chemical engineering problems by computer and mathematical methods.

5101. PRINCIPLES OF CHEMICAL ENGINEERING I. (4 cr; prereq ChEn or MatS major, 5001 or ¶5001; 3 lect, 2 rec hrs per wk) Staff
Material and energy balances applied to chemical engineering systems.

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

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.

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

5105. SCIENTIFIC MODELS FOR CHEMICAL ENGINEERING PROCESSES. (4 cr; prereq sr ChEn or MatS major or IT honors or grad or #; 3 lect hrs per wk)
Physical-chemical validation; time and space scale up and scale down of experiments and models; role of pilot plants and of theory in understanding present and future processes over a sufficient range of space and time scales; generalization and resolution of quantitative models, illustrated by old and new examples.

5201. THERMODYNAMICS AND MATERIAL STATES. (4 cr; prereq upper div ChEn or MatS 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.

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

5301. CHEMICAL REACTOR ANALYSIS. (4 cr; prereq upper div ChEn or MatS 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.

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.

5401. CHEMICAL ENGINEERING LABORATORY. (4 cr per qtr; prereq upper div ChEn or MatS 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.

5402. CHEMICAL ENGINEERING LABORATORY. (4 cr per qtr; prereq upper div ChEn or Mats major, 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.

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

5501. PROCESS EVALUATION AND DESIGN. (4 cr; prereq upper div ChEn or MatS, major or #; 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.

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

5601. PROCESS CONTROL. (4 cr; prereq upper div ChEn or MatS, major 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.

5603. PROCESS CONTROL. (3 cr; prereq 5601 or #; 3 lect hrs per wk)
Advanced topics in chemical process control; synthesis of control structures; multivariable control schemes, optimal control and estimation; computer-aided real-time process control.

5604. PROCESS CONTROL LABORATORY. (2 cr; prereq 5601)
Experiments designed to illustrate and apply control theory. Measurement techniques, calibration, tuning of controls, characterization of sensors and control circuits.

5620. PROCESSING OF POLYMERS AND THEIR COMPOSITES. (3 cr; prereq heat transfer and fluid mechanics or #; 3 lect hrs per wk)
Polymer processing principles and applications: rheology of long chain molecules, flow in simple geometries, die design, mixing, thermal properties, heat transfer, and phase change. Thermoplastic operations—extrusion, forming and molding. Thermoset operations—fiber and particulate reinforced composite molding, pultrusion, and filament winding.

5640. POLYMERIZATION REACTOR ENGINEERING. (3 cr; prereq ChEn reactor design course or #; 3 lect hrs per wk)
Introduction to analysis and design of polymerization reactors. Topics include mathematical modeling techniques, chain-growth and step-growth polymerization, copolymerization, molecular weight distributions, composition, and sequence distributions. Emphasis on application of results. Laboratory offers experience with polymerization processes and molecular weight measurements.

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.

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.

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.

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.

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

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.

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.

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.

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.

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).

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

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

8004. PHYSICAL RATE PROCESSES

8005. PHYSICAL RATE PROCESSES

8101. INTERMEDIATE FLUID MECHANICS

8102. PROBLEMS IN FLUID MECHANICS

8103. TENSORS AND THEORY WITH APPLICATIONS

8104. INTERFACES AND INTERFACIAL PHENOMENA

8105. PRINCIPLES AND APPLICATIONS OF RHEOLOGY

8201-8202-8203. ADVANCED MATHEMATICS FOR CHEMICAL ENGINEERS

8301-8302. PHYSICAL AND CHEMICAL THERMODYNAMICS

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

8403. CHEMICAL REACTION KINETICS—ADVANCED TOPICS

8500. INTERMEDIATE CHEMICAL REACTOR ANALYSIS

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

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

8640. POLYMERIZATION REACTOR ENGINEERING

8701. ANALYSIS OF CHEMICAL ENGINEERING PROBLEMS

8702. ADVANCED TOPICS IN CHEMICAL ENGINEERING

8703. PROCESS CONTROL

8750. ADVANCED CHEMICAL PROCESS DESIGN

8801-8802-8803. SEMINAR

8810. PROCESSING OF ELECTRONIC MATERIALS

8850. GENERAL SURVEY OF CHEMICAL ENGINEERING

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 1004 or 1031. High school chemistry is recommended preparation for all other courses, and students who lack this background will be at a serious disadvantage.

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

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.

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)
Introduction to organic chemistry; emphasis on biological systems.

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

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)
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.

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.

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.

3100. QUANTITATIVE ANALYSIS LECTURE. (3 cr, 3100-3101†; for non-chemistry majors; prereq 1052)
Introduction to the theory of quantitative chemical analysis.

3101. QUANTITATIVE ANALYSIS LABORATORY. (2 cr, 3100-3101†; prereq 3100 or ¶3100; 8 lab hrs per wk)
Introductory laboratory in quantitative chemical analysis.

3301. ELEMENTARY ORGANIC CHEMISTRY I. (4 cr, §3331; for non-chemistry majors; prereq 1052 or equiv; 4 lect hrs per wk)
Important classes of organic compounds, both aliphatic and aromatic, together with some heterocyclic compounds.

3302. ELEMENTARY ORGANIC CHEMISTRY II. (4 cr; prereq 3301, 3305 or ¶3305; if 3305 is taken concurrently, a passing grade in 3305 is required to receive cr for 3302; 4 lect hrs per wk)
Continuation of 3301.

3303. ELEMENTARY ORGANIC CHEMISTRY III. (4 cr; prereq 3302, 3306 or ¶3306; if 3306 is taken concurrently, a passing grade in 3306 is required to receive cr for 3303; 4 lect hrs per wk)
Basic principles with emphasis on organic reaction mechanisms. Intended to coordinate the knowledge acquired in the preceding two quarters.

3305. ELEMENTARY ORGANIC CHEMISTRY LABORATORY I. (2 cr; prereq 3301 or ¶3301; 1 lab conf, 4 lab hrs per wk)
Techniques used in preparing typical organic substances.

3306. ELEMENTARY ORGANIC CHEMISTRY LABORATORY II. (2 cr; prereq 3302 or ¶3302, ¶3305; 1 lab conf, 4 lab hrs per wk)
Techniques used in preparing typical organic substances.

3335H-3336H. HONORS INTRODUCTORY ORGANIC CHEMISTRY II LAB. (5 cr for sequence; prereq 3332 or ¶3332, #, Chem, ChEn, BioC majors only; A-F only)
Laboratory honors section to accompany 3332.

3336. INTRODUCTORY ORGANIC CHEMISTRY III LAB. (3 cr; prereq 3333 or ¶3333 [¶3333 recommended]; A-F only; two 4-hr labs per wk)
Laboratory course to accompany 3333.

3970. DIRECTED STUDY. (Cr ar; prereq #)
On- or off-campus learning experiences, individually arranged between a student and chemistry faculty member, in areas not covered by regular courses.

3991, 3992, 3993. SPECIAL TOPICS IN CHEMISTRY. (1 cr; prereq 1 qtr 1xxx-level chemistry or #; S-N only)
Chemistry topics. Career opportunities and current research.

5122. ADVANCED ANALYTICAL CHEMISTRY. (4 cr; prereq 1 yr organic chemistry, course in thermodynamics)
Equilibria in aqueous and nonaqueous systems.

5126. MODERN ANALYTICAL CHEMISTRY. (4 cr; prereq ChEn major, 3332, 3335; 2 lect, two 3-hr labs per wk)
Strategies and techniques for solving modern analytical problems. Use of modern instruments in analysis.

5127. ANALOG INSTRUMENTATION. (5 cr; prereq Chem major or grad, Phys 1253, Math 1262 or equiv or #)
Basic principles of electronic circuitry; servo systems, operational amplifiers, feedback control, oscillators, and converters for signal processing and control of chemical measurement systems.

5128. THE SMALL COMPUTER IN THE CHEMICAL LABORATORY. (5 cr; prereq 5127 or #; 3 lect, two 4-hr labs per wk)
Applications of the laboratory computer to the control of chemical instrumentation and acquisition of data. Hardware (interfacing) and software (assembly language programming) aspects of automating the chemical experiment.

5130. ANALYTICAL CHEMISTRY. (3 cr; prereq 1 yr organic chemistry with lab; 3 lect, 1 rec 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.

5131. ANALYTICAL CHEMISTRY LABORATORY. (2 cr; prereq 5130 or ¶5130; two 4-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.

5133. CHEMICAL INSTRUMENTATION AND ANALYSIS LECTURE. (3 cr; prereq 1133, 5534, 5535 or #; 3 lect, 1 rec hrs per wk)
Introduction to the methodology and practices of solving analytical problems. Application of modern instrumental techniques.

5139. CHROMATOGRAPHY AND SEPARATION SCIENCE. (3 cr; prereq Chem major or grad, 5133, 5140 or equiv or #)
Fundamental and practical aspects of gas liquid chromatography, modern liquid chromatography, and other techniques used for analysis and separations.

5140. CHEMICAL INSTRUMENTATION AND ANALYSIS LAB. (3 cr; prereq 5133, Chem majors only)
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.

5301. SPECTRAL METHODS FOR ORGANIC QUALITATIVE ANALYSIS. (4 cr, §8302; prereq 3303 or 3333 or equiv; 3 lect, 1 conf hrs per wk)
Practical application of nuclear magnetic resonance, mass, and ultraviolet and infrared spectral analysis to solution of organic structural problems.

5302. ORGANIC SYNTHESIS. (4 cr; prereq 3303 or 3333 or equiv, #; 8 lab, 2 conf hrs per wk)
Reactions of typical functional groups and introduction to modern laboratory methods of organic synthesis.

5305. INTERMEDIATE ORGANIC CHEMISTRY. (4 cr; prereq 3303 or 3333 or equiv; 3 lect, 1 rec hrs per wk)
Introduction to various aspects of physical organic chemistry with application to typical chemical problems. Reactions of typical functional groups and introduction to modern laboratory methods of organic synthesis.

5342. CHEMISTRY OF NATURAL PRODUCTS. (3 cr; prereq 3303 or 3333 or equiv; offered alt yrs)
Biosynthesis of secondary natural products with emphasis on alkaloids, terpenes, and acetogenins.

5344. HETEROCYCLIC COMPOUNDS. (3 cr; prereq 3303 or 3333 or equiv)
Typical classes of heterocyclic compounds, their chemical and physical properties and uses, synthesis.

5520-5521. ELEMENTARY PHYSICAL CHEMISTRY. (3 cr per qtr; prereq 1 yr college chemistry, Phys 1253 or ¶Phys 1253 or Phys 1106, Math 3251)
Brief general survey. 5520: Chemical thermodynamics. 5521: Kinetics, statistical mechanics, molecular structure.

5525. PHYSICAL BIOCHEMISTRY: SOLUTION STRUCTURE AND INTERACTIONS OF BIOLOGICAL MACROMOLECULES. (4 cr, §BioC 5525, §MdBc 5525; prereq 2 qtrs physical chemistry, Biol 5001 or equiv)
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.

5526. PHYSICAL BIOCHEMISTRY: SPECTROSCOPIC METHODS I. (4 cr, §BioC 5526, §MdBc 5526; prereq 2 qtrs physical chemistry)
Lectures on fundamental spectroscopic principles. Emphasis on development of magnetic resonance theory used in study of biological macromolecules.

5527. PHYSICAL BIOCHEMISTRY: SPECTROSCOPIC METHODS II. (4 cr, §BioC 5527, §MdBc 5527; prereq 2 qtrs physical chemistry, BioC/MdBc/Chem 5526 or #)
Application of optical and magnetic resonance techniques to study of structure and dynamics in proteins, lipids, nucleic acids, and synthetic analogs.

5528. PHYSICAL BIOCHEMISTRY: ENZYME KINETICS. (4 cr, §BioC/MdBc 5528; prereq 2 qtrs physical chemistry, BioC/MdBc 5751; BioC 5002 or equiv desirable)
Theory and application of steady-state and transient kinetics to the study of enzymes, enzyme systems, and cellular regulations.

5529. PROTEIN STRUCTURE AND FOLDING. (4 cr, §BioC/MdBc 5529; prereq Biol 5001 or equiv, 1 qtr physical chemistry or #)
Advanced course on protein structure, stability, folding, and molecular modeling. Emphasis on results from X-ray crystallography, solution thermodynamics, NMR, computer graphics, and protein engineering.

5533. QUANTUM CHEMISTRY. (4 cr; prereq 1 yr college chemistry, Math 3252 or ¶Math 3252 or Math 3261 or ¶3261, Phys 1253 or ¶Phys 1253 or Phys 1106 with #)
Principles of quantum mechanics with applications to atomic and molecular structure and to spectroscopy.

5534. CHEMICAL THERMODYNAMICS. (4 cr; prereq upper div IT or CLA Chem major or Δ, Math 3261, Phys 1253 or ¶Phys 1253 or Phys 1106 with #)
Principles of thermodynamics with applications to chemical systems.

5535. STATISTICAL MECHANICS AND REACTION KINETICS. (4 cr; prereq 5534)
(Continuation of 5534) Statistical thermodynamics and the kinetic theory of gases with applications to reaction rate theory. Phenomenological kinetics and experimental methods.

5538. PHYSICAL CHEMISTRY LABORATORY. (1 cr; prereq 5535 or ¶5535; not open to Chem majors)
Experiments in thermodynamics and reaction kinetics.

5540. PHYSICAL CHEMISTRY LABORATORY. (3 cr; prereq 5533, 5535 or 5533, ¶5535 or ¶5533, 5535, Chem majors only)
Laboratory experiments illustrating principles and methods of thermodynamics, reaction kinetics, and quantum mechanics.

5610. PRINCIPLES OF POLYMER SCIENCE. (3 cr, §8610, §MatS 5610; prereq physical chemistry or MatS 5011 or #; 3 lect, 3 lab hrs per wk)
Polymer synthesis and physical chemistry: polymerization kinetics and reactors, molecular weight distribution, network formation, macromolecules in solution and their characterization, the glassy and crystalline state, rubber elasticity, flow and viscoelasticity, environmental degradation.

5731. MAIN GROUP INORGANIC CHEMISTRY. (3 cr; prereq Chem or ChEn major, 5533 or 5534 or ¶5533 or ¶5534; 3 lect, 1 rec hrs per wk)
Structure and bonding concepts in compounds where s and p electrons are important. Descriptive main group inorganic chemistry; symmetry concepts applied to inorganic molecules.

5732. TRANSITION METAL INORGANIC CHEMISTRY. (3 cr; prereq Chem or ChEn major, 5533 or 5534 or ¶5533 or 5534; 3 lect, 1 rec hrs per wk)
Emphasis on transition metal compounds where d electrons are important. Topics of current interest such as organometallic, bioinorganic, and metal cluster chemistry.

5740. INORGANIC CHEMISTRY LABORATORY. (3 cr; prereq 5731, 5732 or 5731, ¶5732 or ¶5731, 5732, Chem majors only)
Laboratory experiments in organic and organometallic chemistry illustrating synthetic and spectroscopic techniques.

5803. THE CHEMISTRY OF INDUSTRY. (4 cr; prereq Chem sr or grad or #)
Relation between basic chemical theory and chemical technology including programs of economics, ecology, and resources.

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.

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*)

8001. APPLIED CHEMICAL THERMODYNAMICS

8002. MECHANISMS OF CHEMICAL REACTIONS

8003. COMPUTATIONAL CHEMISTRY

8104. SPECTROSCOPIC METHODS OF ANALYSIS

8133. MODERN ELECTROANALYTICAL TECHNIQUES, PRINCIPLES, AND PRACTICES

8134. BIOANALYTICAL CHEMISTRY

8135. MASS SPECTROMETRY

8136. SURFACE AND THIN FILM ANALYSIS

8190. SEMINAR: MODERN PROBLEMS IN CHEMISTRY INSTRUMENTATION AND ANALYSIS

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

8290 SEMINAR: MATERIALS CHEMISTRY

8291. SEMINAR PRESENTATION: MATERIALS CHEMISTRY

8301. ADVANCED ORGANIC CHEMISTRY I

8302. INTERPRETATION OF ORGANIC SPECTRA

8304. ADVANCED ORGANIC CHEMISTRY II

8305. ADVANCED ORGANIC CHEMISTRY III

8390. SEMINAR: ORGANIC CHEMISTRY

8391. SEMINAR PRESENTATION: ORGANIC CHEMISTRY

8401. BIOORGANIC CHEMISTRY I

8402. BIOORGANIC CHEMISTRY II

8403. BIOORGANIC CHEMISTRY III

8512. CHEMICAL THERMODYNAMICS

8514. CHEMICAL APPLICATIONS OF GROUP THEORY

8521. METHODS OF THEORETICAL CHEMISTRY

8531-8532-8533. INTRODUCTORY QUANTUM MECHANICS AND SPECTROSCOPY

8535. MOLECULAR QUANTUM MECHANICS

8545. REACTION DYNAMICS

8547. ELEMENTS OF STATISTICAL MECHANICS

8548. ADVANCED STATISTICAL MECHANICS

8560. SEMINAR: PHYSICAL CHEMISTRY OF BIOLOGICAL SYSTEMS

8561. SEMINAR PRESENTATION: BIOLOGICAL SYSTEMS

8590. SEMINAR: PHYSICAL CHEMISTRY

8591. SEMINAR PRESENTATION: PHYSICAL CHEMISTRY

8593. SPECIAL TOPICS IN PHYSICAL CHEMISTRY

8611. INTRODUCTION TO POLYMER PROPERTIES

8612. ADVANCED TOPICS IN POLYMER SCIENCE

8751. PHYSICAL INORGANIC CHEMISTRY I

8752. PHYSICAL INORGANIC CHEMISTRY II

8756. X-RAY CRYSTALLOGRAPHY

8761. ORGANOMETALLIC CHEMISTRY

8762. CHEMISTRY OF THE ELEMENTS

8765. BIOINORGANIC CHEMISTRY

8766. SOLID STATE CHEMISTRY

8790. SEMINAR: MODERN PROBLEMS IN INORGANIC CHEMISTRY

8791. SEMINAR PRESENTATION: MODERN PROBLEMS IN INORGANIC CHEMISTRY

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

8990. RESEARCH IN CHEMISTRY

8991, 8992, 8993. SPECIAL TOPICS IN CHEMISTRY

8994, 8995, 8996. SPECIAL TOPICS IN CHEMISTRY

Civil Engineering (CE)

General Courses

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

3020. COMPUTER APPLICATIONS IN CIVIL ENGINEERING I. (4 cr; prereq CE or GeoE or MinE students Math 1231)
Introduction to 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.

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.

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

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.

5002. ENGINEERING ECONOMICS. (2 cr; prereq IT jr or above, adult special 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.

5004. UNDERGROUND CONSTRUCTION ENGINEERING. (4 cr; prereq upper div IT, 5003)
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.

5005. PUBLIC WORKS INFORMATION SYSTEMS. (4 cr; prereq upper div IT or grad student, 3020 or equiv or #)
Development, purpose, and components of management information systems. Geographic database and geocoding. Public works facility inventory, management of maintenance operations, and computer-aided mapping and design. Capital budgeting and financing for public works.

5010. SENIOR DESIGN PROJECT. (5 cr; prereq CE sr; 3 lect, 6 lab 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.

5021. COMPUTER APPLICATIONS IN CIVIL ENGINEERING II. (4 cr; prereq CE, GeoE, MinE 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.

5055. ENGINEERING GEOSTATISTICS. (4 cr, §GeoE 5437; prereq Stat 3091, CE or GeoE or MinE 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.

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 laboratory 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.

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.

Surveying and Mapping

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. Use of aerial photographs for mapping. Fundamentals of geometrics for design, grades, and vertical and horizontal curvature.

5102. SITE AND ROUTE ENGINEERING. (4 cr; prereq IT or grad student, 3100; 3 lect, 3 lab hrs per wk)
Site and route design fundamentals and problems based on spatial data obtained through photogrammetric mapping. Problems in geometric design; grades, horizontal and vertical curves; fitting of design to topography; earthwork, area and volumes; and drainage. Construction control and layout.

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; principles of photo interpretation; elements of remote sensing; and applications to resource evaluation.

Transportation

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.

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.

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.

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.

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)

3300. ELEMENTS OF SOIL MECHANICS. (4 cr; prereq IT student, AEM 3016; 4 lect hrs per wk)
Physical properties of soils; soil classification. Stresses and strains. Strength and deformability. Permeability and seepage. One-dimensional consolidation.

3301. SOIL MECHANICS LABORATORY. (1 cr; prereq IT student, 3300; 4 lab hrs for 5 wks)
Index tests; consolidation; triaxial compression; unconfined compression; permeability and direct shear.

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.

5301. FOUNDATION ENGINEERING. (4 cr; prereq upper div IT or grad student, 3300, 3301)
Settlement analysis. Retaining walls and earth pressure theories. Stability of slopes. Bearing capacity of shallow foundations. Deep foundations.

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

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.

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.

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.

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.

5405. HYDROLOGY AND HYDROLOGIC DESIGN. (4 cr; prereq IT or grad student, 3400 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.

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.

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.

5426. COMPUTER MODELING OF GROUND WATER 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.

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

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.

5501. ANALYSIS AND DESIGN OF WASTEWATER SYSTEMS. (4 cr; prereq IT or grad student, Chem 1005, 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.

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.

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.

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.

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.

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.

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.

Structural Engineering

3600-3601-3602. STRUCTURAL DESIGN FOR ARCHITECTS. (4 cr per qtr; prereq adult special 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

8097-8098-8099. CIVIL ENGINEERING RESEARCH

8200. THEORY OF TRAFFIC FLOW

8201. URBAN TRAFFIC OPERATIONS

8202. FREEWAY TRAFFIC OPERATIONS

8210. MODELING CONSUMER CHOICES IN TRANSPORTATION

8211. TRAVEL DEMAND FORECASTING

8214. TRANSPORTATION SYSTEMS DYNAMICS AND CONTROL

8322. STORAGE AND FLOW OF GRANULAR MATERIALS

8401. INTERMEDIATE FLUID MECHANICS II

8402. INTERMEDIATE FLUID MECHANICS III

8407. STOCHASTIC HYDROLOGY

8413. MECHANICS OF SEDIMENT TRANSPORT

8416. HYDRAULIC MEASUREMENTS

8418. COMPUTATIONAL HYDRODYNAMICS I

8419. COMPUTATIONAL HYDRODYNAMICS II

8424. HYDRAULIC TRANSIENTS

8425. ADVANCED GROUNDWATER MECHANICS

8440. FLOW EFFECTS ON STRUCTURES

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

8501. PHYSICAL AND CHEMICAL PROCESSES FOR WATER AND WASTEWATER TREATMENT

8502. BIOLOGICAL AND CHEMICAL PROCESSES FOR WASTEWATER TREATMENT

8505, 8506. AQUATIC CHEMISTRY FOR ENVIRONMENTAL ENGINEERS

8507. ENVIRONMENTAL PROCESSING OF ORGANIC MATERIALS

8521. WASTEWATER TREATMENT PLANT DESIGN

8540. INTERFACIAL MASS TRANSFER WITH ENVIRONMENTAL APPLICATIONS

8550. ANALYSIS AND MODELING OF AQUATIC ENVIRONMENTS

8551. SEMINAR ON MODELS OF AQUATIC ENVIRONMENTS

8560. SEMINAR: SPECIAL TOPICS IN ENVIRONMENTAL ENGINEERING

8605. THE FINITE ELEMENT METHOD IN CIVIL ENGINEERING

8606. APPROXIMATE METHODS OF STRUCTURAL ANALYSIS

8608. ADVANCED THEORY OF STRUCTURES

8609. PRINCIPLES OF STRUCTURAL STABILITY

8610. SHELL STRUCTURES

8611. PLATE STRUCTURES

8612. PLASTIC DESIGN OF STEEL STRUCTURES

8616. NONLINEAR STRUCTURAL SYSTEMS

8620-8621. STRUCTURAL DYNAMICS I-II

8622. DYNAMIC SOIL-STRUCTURAL ANALYSIS

8625. BEHAVIOR OF REINFORCED CONCRETE STRUCTURES I

8626. BEHAVIOR OF REINFORCED CONCRETE STRUCTURES II

8697-8698-8699. SEMINAR: STRUCTURES

Computer Science (CSci)

3001. PERSPECTIVES ON COMPUTERS AND SOCIETY. (4 cr, §NatSci 3201; prereq soph or #; informal lab)
Impact of computers on society. Partnership or confrontation. History of development. Potential for use. Computer utility. Benefits and potential problems. Chip technology and CAD. Software development and maintenance. Computer networks. Personal computers and supercomputers. Use and misuse of computers. Computer graphics. Artificial intelligence. Computer-based education. Applications in the office, business, and industry.

3101. INTRODUCTION TO COMPUTER APPLICATIONS FOR SCIENTISTS AND ENGINEERS. (4 cr; prereq 1 qtr calculus)
Algorithm development and principles of computer programming using FORTRAN, emphasizing numerical methods for science and engineering applications. Integral open laboratory.

3102. INTRODUCTION TO PASCAL PROGRAMMING. (4 cr; prereq non-CSci major, Math 1111 or 1201 or equiv or #; informal lab)
PASCAL computer language, applications, programming techniques. Designed to bring students to advanced-level competence in PASCAL programming.

3113. INTRODUCTION TO PROGRAMMING IN C. (4 cr; prereq 3101 or 3102 or any programming experience, precalculus or #)
Intensive introduction to syntax and semantics of the C language, with introduction to UNIX tools for implementing C programs. Students write programs, use debugging aids, and build libraries.

3121. SURVEY OF DATA STRUCTURES AND ALGORITHMS. (4 cr, §3105, 3321; prereq 3102 or 3113 or #)
Fundamental structures of computer science, including induction, mathematical analysis of computational complexity, and the definition and implementation of selected data structures along with their fundamental operations. Students implement some of these data structures in computer programs.

3204H. INTRODUCTION TO PROGRAMMING AND PROBLEM SOLVING IN SCIENCE AND ENGINEERING, PART I. (2 cr; prereq selection for IT honors curriculum or consent of IT Honors Office, H Calc I; A-F only)
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.

3205H. INTRODUCTION TO PROGRAMMING AND PROBLEM SOLVING IN SCIENCE AND ENGINEERING, PART II. (2 cr; prereq selection for IT honors curriculum or consent of IT Honors Office, H3204, H Calc II; A-F only)
Concept of library and its use, "Black Box" approach to problem solving. Examples from root finding of nonlinear equations, systems of linear equations and ordinary differential equations in solution to engineering problems. Modularization of larger programs, user defined subprograms. Communication between subprograms through variable scoping and parameters. Short introduction to FORTRAN modularization and connection with PASCAL programs. Structured data types: multidimensional arrays, records, sets. Complex numbers and applications.

3311. DISCRETE STRUCTURES OF COMPUTER SCIENCE. (4 cr, §3400; prereq 1 qtr calculus or #)
Mathematical techniques and structures in computer science. Formal logic, elementary combinatorics, induction, recurrences, relations and graphs.

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.

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. Scheme language used for illustrating ideas and lab problems.

3321. ALGORITHMS AND DATA STRUCTURES I. (4 cr, §3105, 3121; prereq 3311, 3316 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.

3322. ALGORITHMS AND DATA STRUCTURES II. (4 cr, §5121; prereq 3317, 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++ language.

3327. INTRODUCTION TO ORGANIZATION OF COMPUTER SYSTEMS. (4 cr, §3107, 5101; prereq 3316 or 3121)
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).

5001. THEORY AND APPLICATION OF LINEAR PROGRAMMING ALGORITHMS. (4 cr; 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.

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

5101. INTRODUCTION TO ORGANIZATION OF COMPUTER SYSTEMS. (4 cr, §3107, 3327; prereq non-CSci major, 3316 or 3121 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).

5102. STRUCTURE AND PROGRAMMING OF SOFTWARE SYSTEMS II. (4 cr; prereq 3327 or 5101 or #; informal lab)
Extension of basic machine architecture and principles of system programming; closed subroutines; parameter passing mechanisms; macros and conditional assembly; input-output; assembly linking and loading; dynamic resource allocation; introduction to operating systems, job control language, and processes.

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 queueing 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.

5105. THEORY OF MACHINE ARITHMETIC. (4 cr; prereq 3327 or 5101 or #; informal lab)
Residue class arithmetic. Congruences and complement arithmetic. Integral additive and subtractive accumulators. Applications to absolute values and sign arithmetic, scaling and floating point operations.

5106. STRUCTURE OF HIGHER LEVEL LANGUAGES. (4 cr; prereq 3322, 5102 or #)
Formal definition of the syntax and semantics of programming languages; semantics both by means of interpreters and by using the axiomatic approach. Concepts underlying programming languages and their implementations in a selected group of languages. Program description at compilation time and execution time.

5107. COMPUTER GRAPHICS I. (4 cr; prereq 3322, 3327 or #)
Definition of interactive computer graphics, its goals and its problems. A model system. Data structures for computer graphics, picture structure and transformations. Structures of graphical programming languages. Interaction handling. Raster graphics.

5117. COMPUTER GRAPHICS II. (4 cr; prereq 5107 or #; informal lab)
Introduction to vector geometry. Three-dimensional modeling and viewing transformations. Perspective view generation and 3D clipping. Introduction to curves and surfaces. Hidden line and hidden surface removal. Realistic image generation. Advanced display system architectures. Modeling of 3D graphics programming.

5121. ALGORITHMS AND DATA STRUCTURES II. (4 cr, §3322; prereq non-CSci major, 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++ language.

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.

5151-5152. INTRODUCTION TO PARALLEL COMPUTING I-II. (4 cr each; prereq 3121 or 3322)
Programming techniques, algorithms, data structures. Evaluation of algorithm quality. Effectiveness and scalability. 5151: Basic concepts and algorithms for parallel computation. 5152: Parallel algorithms for a variety of problems.

5180. SOFTWARE ENGINEERING I. (4 cr; prereq 5106; informal lab)
Emphasis on abstractions as vehicle for analysis, design, and testing and on modules as vehicle for implementation. Software life cycle and project data bases. PSL/PSA. Actor model of computation, process, and data modeling. Specification language MSG. Use of abstractions in functional, architectural, and module design. Test case selection and reliability assessment. Systematic coding: invariants and representation functions.

5181. SOFTWARE ENGINEERING II. (5 cr; prereq 5180; scheduled lab)
Requirements 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 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 specific systems.

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

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

5205. PARALLEL COMPUTER ARCHITECTURE. (4 cr; prereq 5201 or #)
Parallel computer system analysis and design. Organizational dependence on computations to be performed. Study of the primary components of parallel architectures (processors, control units, memories, interconnection networks). Implemented paradigms of pipelines and vector processors, array processors, and multiprocessors.

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

5279. COMPUTER-AIDED DESIGN OF COMPUTERS. (4 cr; prereq basic knowledge of computer architecture and elements of computers, 5201)
Behavioral, structural, functional, and gate circuit simulation of design. Algorithms for partitioning, placement, routing, and design or rule check.

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

5281. COMPUTER-AIDED DESIGN OF VLSI. (4 cr; prereq exper with data structures; 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.

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

5301. NUMERICAL COMPUTATION. (4 cr; prereq Math 3261 or #; knowledge of PASCAL or FORTRAN assumed; informal lab)
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.

5302. ANALYSIS OF NUMERICAL ALGORITHMS. (4 cr; prereq 5301 or #; informal lab)
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 solution of ordinary differential equations.

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.

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.

5306. NUMERICAL METHODS FOR PARTIAL DIFFERENTIAL EQUATIONS. (4 cr; prereq 5302, differential equations or advanced calculus)
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.

5307. NUMERICAL ALGORITHMS FOR PARALLEL COMPUTERS. (4 cr; prereq upper div IT or CLA CSci major or grad, 5301, 5302 or #)
Basic concepts of vectorization and parallelization. Parallel matrix multiplication. Parallel factorization for dense linear systems (LU, QR). Parallel solution of triangular and banded linear systems. Parallel methods for the eigenvalue problem and sparse linear problems.

5314. INTRODUCTION TO SPARSE MATRIX TECHNIQUES. (4 cr; prereq 5304, programming exper equiv to 3321)
Sparse matrices: too big to fit in memory. Sources of sparse matrices. Reducing profile: reverse Cuthill Mckee, general methods, elimination trees, fill-in. Reducing fill: minimum degree, nested dissection. Pivoting strategies and storage schemes. Iterative methods: matrix splittings, Jacobi, relaxation, preconditioning.

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

5400. INTRODUCTION TO AUTOMATA THEORY. (4 cr; prereq 3311, 3321 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.

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

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

5502. INTRODUCTION TO OPERATING SYSTEMS. (4 cr; prereq 3322, 5102 or #; informal lab)
Definition and historical development of operating systems. Abstractions and implementations of features common to most systems. Concurrency and related control problems. Resource allocation. Storage allocation. Process manager and the kernel of an operating system. Sharing. Capability-based addressing. Protection. Performance measurement and analysis.

5504. INTRODUCTION TO COMPILERS. (4 cr; prereq 5106 or #; informal lab)
Lexical scanning together with preprocessing and macro expansion, symbol tables, parsing, intermediate text generation, error detection and correction. Students design and implement a front end for a compiler.

5505. INTRODUCTION TO COMPILERS. (4 cr; prereq 5504 or #)
A higher-level language L, machine language loaders, linkage editors; mapping L onto machine language, code generation techniques; derivation of an intermediate language and implementation of code generators (from intermediate onto machine language). Students write the back end of a compiler.

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.

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.

5521. PATTERN RECOGNITION. (4 cr; prereq 5301, Stat 3091 or #; informal lab)
Pattern recognition, feature selection, measurement techniques, and similar problems. Classification methods: statistical decision theory, nonstatistical techniques. Automatic feature selection. Syntactic pattern recognition. The relationship between mathematical pattern recognition and artificial intelligence. Applications.

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.

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

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

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

5702. THE PRINCIPLES OF DATA BASE SYSTEMS. (4 cr; prereq 5122 or #; informal lab)
Fundamental concepts. Conceptual data organization. Data models. Data manipulation languages. Data base design. Security and integrity. Performance evaluation. Query optimization. Distributed data base systems.

5703. DATA BASE SYSTEM DESIGN. (4 cr; prereq 5702 or #; informal lab)
Application of data base concepts to the design and development of data base systems and data base applications. Design of current commercial and research-oriented data base systems. Techniques of using data base systems for applications.

5799. PROBLEMS IN INFORMATION SCIENCE. (1-4 cr per qtr; prereq #; same number may be used for more than one qtr)
Special course or individual study arranged with faculty member.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

8101. ADVANCED OPERATING SYSTEMS

8102. OPERATING SYSTEMS THEORY

8103. DISTRIBUTED AND PARALLEL PROGRAMMING

8199. SEMINAR: LANGUAGES AND SYSTEMS

8299. SEMINAR: MACHINE DESIGN

8301-8302. COMPUTATION OF SPECIAL FUNCTIONS AND FORMULAS

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

8307. ADVANCED PARALLEL NUMERICAL METHODS

8314. ITERATIVE METHODS FOR LINEAR SYSTEMS

8320. NUMERICAL SOLUTION OF LINEAR LEAST SQUARES PROBLEMS

8330. PARALLEL METHODS FOR NUMERICAL OPTIMIZATION

8399. SEMINAR: NUMERICAL ANALYSIS

8401-8402. ALGORITHMS—TECHNIQUES AND THEORY

8403-8404. THEORY OF COMPUTATION

8499. SEMINAR: COMPUTATIONAL THEORY AND LOGIC

8505. OPTIMIZATION IN COMPILERS

8511. SPECIAL CONCEPTS IN ARTIFICIAL INTELLIGENCE

8521. NEUROCOMPUTING AND NEURAL NETWORKS

8551. ARTIFICIAL INTELLIGENCE TECHNIQUES IN ROBOTICS

8561. READINGS IN COMPUTATIONAL VISION

8571. READINGS IN EXPERT SYSTEMS

8581. READINGS IN PARALLEL SYMBOLIC COMPUTING

8599. SEMINAR: ARTIFICIAL INTELLIGENCE

8699. SEMINAR: CONTROL SCIENCE

8701. ADVANCED TOPICS IN DATA BASE SYSTEMS

8799. SEMINAR: INFORMATION SCIENCE

8899. COLLOQUIUM: COMPUTER SCIENCE

Electrical Engineering (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.

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

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.

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

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.

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

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.

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

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.

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.

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.

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.

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

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 laboratory.

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 laboratory.

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.

3470-3471. SUMMER ENGINEERING EMPLOYMENT. (1-3 cr per qtr; prereq completion of 2nd- or 3rd-yr work, declaration of intention before end of spring qtr, regis in fall qtr, #)
Summer work in an engineering field; minimum of 360 hours per summer. Requires a technical report.

3476-3477. 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.

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.

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.

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, use to predict system performance. Comparison of performance and topology of various logic families including TTL, MOS, CMOS, I2L, and ECL.

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.

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

5062. COMMUNICATION CIRCUITS. (3 cr; prereq upper div EE or grad IT major, 3012, 5055 or #)
Design and analysis of electronic circuits common to communication systems and instrumentation, incorporating the latest IC technology. Typical circuits include tuned amplifiers, mixers, modulators, and phase-locked loops.

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

5091. COMMUNICATION CIRCUITS LABORATORY. (1 cr; prereq 3402 or ¶3402, ¶5062)

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.

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.

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.

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.

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.

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

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

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.

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.

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

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

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.

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

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.

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.

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 laboratory.

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.

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

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.

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

5500-5501-5502. DESIGN OF ACTIVE AND PASSIVE ANALOG FILTERS. (3 cr per qtr; prereq grad standing or #)
5500: Brief review of some network and analysis concepts (system equations; poles and zeros; one-port (impedance) and two-port (transfer) functions; two-port parameters; LC impedance synthesis; approximation theory (Butterworth, Chebyshev, Elliptic, General, Thompson functions); computer aids; frequency transformation; computer-aided design of passive filters (LC Ladders, lattice networks).
5501: Theory of sensitivity and tolerances; elements of active network design; design of optimized second-order active filters (biquads); methods for the design of higher-order active filters.
5502: Fully integrated monolithic analog filters; the design and performance problem, need for automatic tuning; methods for automatic tuning; realization procedures for continuous-time IC filters; principles of sampled-data switched-capacitor filters; design methods of switched-capacitor filters.

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.

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.

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 concolution. Finite impulse response filter design approaches and techniques. Infinite impulse response filter design approaches and techniques. Quantization.

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

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.

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.

5560. BIOMEDICAL INSTRUMENTATION. (4 cr; prereq #)
Biological signal sources. Electrodes, microelectrodes, other transducers. Characteristics of amplifiers for biomedical applications. Noise in biological signals. Filtering, recording, and display. Protection of patients from electrical hazard. Experiments in neural and muscle stimulation, EKG and EMG recording, neuron simulation, filtering and low-noise amplifiers.

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.

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.

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.

5574-5575†. COMPUTER-AIDED VLSI DESIGN LABORATORY. (3 cr per qtr; prereq IT sr or grad IT major or IT adult special 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.

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).

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.

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.

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.

5620. ENGINEERING ACOUSTICS. (4 cr; prereq IT sr or grad IT major or IT adult special or #)
Radiation and reception of acoustic waves. Acoustic sensors. Waveguides, cavities, and wave filters. Acousto-electric analogies and transducers. Methods of linear acoustic wave system theory applied to underwater sound, speech processing, and imaging.

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.

5630. CONTEMPORARY OPTICS. (4 cr; prereq 3111 or Phys 5024 or #)
Current developments in optics. Theory of lasers and their applications in holography, nonlinear optics, etc. Nonlinear optics. Optics of anisotropic media. Theory of image formation and spatial filtering. Properties of optical detectors.

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.

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. Topics of current interest.

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.

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. Topics of current interest.

5650. PHYSICAL METHODS IN SOLID STATE MATERIALS I. (3 cr; prereq EE sr or grad or adult special, 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.

5651. PHYSICAL METHODS IN SOLID STATE MATERIALS II. (3 cr; prereq EE sr or grad or adult special, 5650 or #)
Applying quantum theory to solid state materials. Schrodinger'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.

5652. PHYSICAL METHODS IN SOLID STATE MATERIALS III. (3 cr; prereq EE sr or grad or adult special, 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.

5661. SEMICONDUCTOR PROPERTIES AND DEVICES I. (3 cr; prereq EE sr or grad or adult special, 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.

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

5666-5667-5668. MAGNETIC PROPERTIES OF MATERIALS AND APPLICATIONS. (3 cr per qtr; prereq #)
5666: Magnetic measurement techniques, physical principles of magnetism, and properties of magnetic materials with applications.
5667: Physical principles of crystalline and induced magnetic anisotropy, magnetostriction, magnetic domains and the magnetization process, fine particles and thin films and magnetization dynamics.
5668: Properties of soft and hard magnetic materials with applications such as thin film memories, permanent magnets, magnetic recording, and magneto-optics.

5669. MAGNETIC RECORDING. (3 cr; prereq #)
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.

5670. BASIC MICROELECTRONICS. (4 cr; prereq #)
Experimental and theoretical studies of the basic physical processes used in microelectronic device fabrication. Transistor and integrated circuit layout, fabrication, and evaluation.

5671. ADVANCED MICROELECTRONICS. (2 cr; prereq IT sr or IT grad, 5670 or ¶5672 or #)
Integrating unit processes into a fabrication technology, and the physics and chemistry of such advanced techniques as molecular beam epitaxy, electron beam lithography, and reactive ion etching.

5672. ADVANCED MICROELECTRONICS LABORATORY. (1 cr; prereq IT sr or IT grad, 5670 or ¶5671 or #)
Design, fabrication, and testing of an MSI level-integrated circuit. Familiarity with the unit operations.

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. Laboratory.

5700. INFORMATION THEORY AND CODING. (3 cr; prereq IT sr or grad or adult special, Stat 3091 or #)
Discrete information sources and channels, source encoding, the binary channel and Shannon's theorem. Block codes for the binary channel.

5702. STOCHASTIC PROCESSES AND OPTIMUM FILTERING. (3 cr; prereq Stat 3091, grad standing or #)
Stochastic processes, linear system response to stochastic inputs. Gaussian process, Markov process. Linear filtering, maximum likelihood estimate, stochastic control.

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 connection coding; trellis-coded modulation.

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.

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.

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.

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.

5760. BIOLOGICAL SYSTEM MODELING AND ANALYSIS. (4 cr; prereq #)
Purposes of biological system modeling; advantages, limitations, and special problems. Models of nerve excitation and propagation. Biological control systems: respiratory system, cardiovascular system. Sensory organs and various theories of perception. Limbs and locomotion.

5802. ELECTRIC POWER SYSTEM ANALYSIS. (3 cr; prereq IT grad standing 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.

5803-5804. POWER GENERATION, OPERATION, AND CONTROL. (3 cr each; prereq grad IT major, 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.

5805. ELECTRIC POWER SYSTEM ENGINEERING. (3 cr; prereq IT grad standing 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.

5807. POWER SYSTEM PROTECTION. (3 cr; prereq IT grad standing 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.

5814. SWITCHED MODE POWER ELECTRONICS. (3 cr; prereq IT sr or IT grad standing or IT adult special, 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.

5815. SWITCHED MODE POWER ELECTRONICS II. (3 cr; prereq IT sr or grad or IT adult special, 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.

5816. SWITCHED MODE POWER ELECTRONICS LABORATORY. (2 cr; prereq IT sr or IT grad standing or IT adult special, ¶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.

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.

5825. FINITE-ELEMENT METHODS IN ELECTRICAL ENGINEERING. (3 cr; prereq IT grad or EE sr, #)
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.

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.

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.

5854. ADVANCED COMPUTER NETWORKS. (3 cr; prereq grad IT major or EE adult special, CSci 5211 or #)
International Standards Organization (ISO) network architecture. Topology analysis. Data communication. Satellite and packet radio networks. Distributed systems and case studies.

5856-5857. PARALLEL COMPUTING. (3 cr per qtr; prereq grad IT major, 5852, 5853 or #)
Computational model for parallel computing; fundamental parallel operations; parallel machine architectures; programming tools and case studies.

5858. COMPUTER ARCHITECTURE. (3 cr; prereq IT sr or IT grad standing or IT adult special, 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.

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 laboratory.

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.

5952. SPECIAL TOPICS IN ELECTRICAL ENGINEERING. (3 cr [may be repeated for cr]; prereq IT grad student or adult special or #)
Topics vary.

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

8060. ADVANCED BIPOLAR TRANSISTOR THEORY

8090. ELECTRONICS SEMINAR

8100-8101. ADVANCED ENGINEERING ELECTROMAGNETICS

8110-8111. PLASMA PHYSICS

8120-8121-8122. FUNDAMENTALS OF ACOUSTICS

8140. SEMINAR: PLASMA PHYSICS

8143. SEMINAR: MODERN OPTICS

8153-8154. PROPERTIES OF SEMICONDUCTORS

8156-8157-8158. FERROMAGNETISM AND RELATED PHENOMENA

8160. QUANTUM ELECTRONICS I

8164. QUANTUM ELECTRONICS II (GUIDED WAVE OPTICS)

8170. FLUCTUATION PHENOMENA

8180. ADVANCED ANALOG INTEGRATED CIRCUITS

8181. ADVANCED DIGITAL INTEGRATED CIRCUITS

8190. SEMINAR: QUANTUM ELECTRONICS

8191. SEMINAR: SURFACE PHYSICS

8192. SEMINAR: MAGNETICS

8203-8204. SIGNAL DETECTION AND ESTIMATION THEORY WITH APPLICATIONS

8205. IMAGE PROCESSING AND APPLICATIONS

8206. IMAGE UNDERSTANDING AND APPLICATIONS

8207. VLSI SIGNAL PROCESSING

8211. CODING THEORY

8212. CODING THEORY II

8220. TOPICS IN STATISTICAL THEORY OF COMMUNICATION

8240. SEMINAR: COMMUNICATION

8250-8251-8252. ADVANCED CONTROL TOPICS

8253. TOPICS IN LARGE-SCALE SYSTEM

8256. TOPICS IN STOCHASTIC FILTERING AND CONTROL

8257, 8258. ADVANCED SYSTEMS THEORY I, II

8260. TOPICS IN NONLINEAR SYSTEMS

8290. SEMINAR: CONTROL THEORY

8291. SEMINAR: SYSTEM THEORY

8300-8301. ADVANCED POWER SYSTEM TOPICS

8305. SPARSE MATRIX METHODS IN POWER SYSTEM ANALYSIS

8340. SEMINAR: ELECTRIC POWER

8341. SEMINAR: ENERGY CONVERSION

8342. POWER ELECTRONICS: UTILITY APPLICATIONS

8352. FAULT DIAGNOSIS AND RELIABLE DESIGN

8353. SEQUENTIAL CIRCUIT THEORY

8359. COMPUTING WITH NEURAL NETWORKS

8360. LOCAL AREA NETWORKS

8362. ADVANCED COMPUTER ARCHITECTURE

8363-8364. PARALLEL PROCESSING I-II

8370. DESIGN OF INTELLIGENT SYSTEMS

8390. COMPUTER SYSTEMS SEMINAR

8450. SPECIAL INVESTIGATIONS

8451. ADVANCED TOPICS IN ELECTRICAL ENGINEERING

8460. PLAN B PROJECT

8461. PLAN B PROJECT

8490, 8491, 8492. GRADUATE SEMINAR

Extractive Metallurgical Engineering (MetE)

For Graduate Students Only

(For descriptions, see *Graduate School Bulletin*)

8000-8001. APPLIED PROCESS METALLURGY I-II

8401-8402-8403. SEMINAR IN METALLURGICAL ENGINEERING

8830. ELECTRIC AND MAGNETIC SEPARATION OF MINERALS

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

8842. SURFACE CHEMISTRY OF MINERAL SUSPENSIONS

8921-8922-8923. RESEARCH IN EXTRACTIVE METALLURGICAL ENGINEERING

8930-8932-8934. PHYSICAL CHEMISTRY OF HIGH TEMPERATURE METALLURGICAL REACTIONS I-II-III

Geological Engineering (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.

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.

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.

5302. APPLIED ROCK MECHANICS. (4 cr; prereq IT student or grad IT major, 5300)
Principles and techniques of site investigation in rock. Design of surface and underground excavations, including excavation and mine stability, and methods of ground control. Application of numerical models in design.

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.

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.

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.

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*)

8336. BOUNDARY ELEMENT METHODS I

8338. BOUNDARY ELEMENT METHODS II

8350-8352. ADVANCED ROCK MECHANICS I-II

8601-8602-8603. SEMINAR

8612-8613-8614. RESEARCH PROBLEMS

Geology and Geophysics (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.

1002w. 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.

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.

1011w. 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.

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.

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.

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 laboratory 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.

1022s. HISTORICAL GEOLOGY. (4 cr, §1002; prereq 1001, 1021; 3 lect, one 2-hr lab hrs per wk) Sloan
Evolution of the Earth from its origin to the present, changes in continental structure and biology through the past 4.6 billion years.

1601w. OCEANOGRAPHY. (4 cr; 3 lect, 1 lab hrs per wk) Barnwell, Paola, Shapiro
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.

3201. GEODYNAMICS I: THE SOLID EARTH. (4 cr; prereq Phys 1251, 1252) Karato, Teyssier
Introduction to the dynamics of the solid Earth, particularly the tectonic system.

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.

3211s. HONORS EARTH SCIENCE. (4 cr, §1001, §1021, §1111; 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.

3301. GEOCHEMICAL PRINCIPLES. (4 cr; prereq Chem 1051, 1052) Seyfried, Stout
Introduction to the Earth's chemistry.

3401w. INTRODUCTORY MINERALOGY. (4 cr, §5004, 5404; prereq 1001 or 1111, 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. Laboratory includes crystallographic, polarizing microscope, X-ray powder diffraction exercises, and hand-specimen mineral identification.

3402s. PETROLOGY. (4 cr; prereq 3401 or #) Edwards, Weiblen
Introduction to lithologic character and genesis of igneous and metamorphic rocks.

3990. PROBLEMS IN GEOLOGY. (1-6 cr; prereq #, Δ)
Research or problem selected on basis of individual interests and background.

5004w. MINERALOGY. (4 cr, §3401; not open to Geo or Geophys or GeoE or MinE majors; prereq Chem 1051, Math 1252, #; 3 lect, 4 lab hrs per wk) Staff
For description, see 3401.

5010. FIELD WORKSHOP. (2 cr; prereq Geo or Geophys or GeoE major or #) Staff
Geologic or geophysical field study.

5020. LABORATORY WORKSHOP. (2 cr; prereq Geo or Geophys or GeoE major or #) Staff
Geologic or geophysical laboratory study.

5030. MODELING WORKSHOP. (2 cr; prereq Geo or Geophys or GeoE major or #) Staff
Modeling of geologic or geophysical systems.

5051su,CEE. PHYSICAL GEOLOGY FOR TEACHERS. (4 cr, §1001; prereq education 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.

5052su,CEE. HISTORICAL GEOLOGY FOR TEACHERS. (4 cr, §1002; prereq education 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. Laboratory, fieldwork, and seminar.

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.

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.

5111su. FIELD GEOLOGY. (5-9 cr; prereq 5201, #; open only to Geo, Geophys, and GeoE majors)
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. Major report on fieldwork required.

5151f. INTRODUCTION TO PALEONTOLOGY. (5 cr; prereq 1002, 1022 or #) Sloan
Introduction to morphology, classification, and ecology of selected major fossil groups.

5154w. VERTEBRATE PALEONTOLOGY I. (5 cr; prereq 5151 or EEB 5114) Sloan
Morphology, evolution, and stratigraphic distribution of fossil fish, amphibians, reptiles, and birds.

5155s. VERTEBRATE PALEONTOLOGY II. (5 cr; prereq 5154 or EEB 5114) Sloan
Morphology, evolution, and stratigraphic distribution of fossil mammals.

5201s. STRUCTURAL GEOLOGY. (5 cr; prereq 3401, 3402 or #; IT: upper div major in Geo or Geophys or GeoE or MinE; CLA: jr or sr Geo major) Teyssier
Primary and secondary structures of rocks, mechanics and modes of deformation, introduction to field methods in geology. Field trips.

5202. TECTONIC STYLES. (3 cr; prereq 5201 or #; 3 lect hrs per wk; offered 1994 and 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.

5203w. GEOTECTONICS. (3 cr; prereq 5201 or #; offered 1994 and 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.

5251s. GEOMORPHOLOGY. (4 cr [5 cr with term project]; prereq 1001, Math 1111 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.

5252w. REGIONAL GEOMORPHOLOGY. (3 cr; prereq 5201 or #; offered 1994 and 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.

5255w. GLACIOLOGY. (4 cr [5 cr with term project]; prereq Math 3261 or equiv or #) Hooke
Theories of glacier flow. Internal structures and heat flow in glaciers and ice sheets. Reading assignments and problems.

5261f. GLACIAL GEOLOGY. (4 cr [5 cr with term paper or 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.

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.

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.

5321. ISOTOPE GEOLOGY. (4 cr; prereq 3301 or #) Alexander, Ito
Introduction to theory and uses of radioactive, radiogenic, and stable isotopes in geology. Radioactive dating, geothermometry, and tracer techniques in geologic processes.

5405. OPTICAL MINERALOGY. (2 cr; prereq 3401 or ¶3401) Staff
Optical properties of minerals; symmetry and crystal optics; identifying minerals using the polarizing microscope.

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. Laboratory, field trip, problem sets, term paper.

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 of geologic interpretation, radioactivity and thermal structure of the Earth, physical basis for plate tectonics.

5505f. SOLID-EARTH GEOPHYSICS I. (4 cr; prereq 3201, Phys 1253)
Earthquake seismology; physical structure of the Earth's crust and deep interior, Earth's gravity field.

5506w. SOLID-EARTH GEOPHYSICS II. (4 cr; prereq 3201, Phys 1253) Staff
Gravity and magnetic fields of the Earth; paleomagnetism, thermal history of the Earth.

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.

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.

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.

5521. DATA PROCESSING METHODS IN GEOPHYSICS. (3 cr; prereq 5512, 1 yr calculus)
Digital data processing techniques used in geophysical exploration.

5535w. GEOLOGICAL THERMOMECHANICAL MODELING. (4 cr; prereq Math 3261 or #) 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.

5536s. APPLICATIONS OF FLUID MECHANICS TO GEOLOGICAL PROBLEMS. (4 cr; prereq 1 yr calculus, AEM 3200 or CE 3400 or #) Yuen
Scaling equations for geological approximations, applications to geological situations, rheology.

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.

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.

5601f. LIMNOLOGY. (4 cr, §EEB 5601; prereq Chem 1052 or equiv) Shapiro
Events occurring in lakes, reservoirs, and ponds, from their origins through their physics, chemistry, and biology. Emphasis on interrelationships of these parameters and on effects of civilization on lakes.

5603. GEOLOGICAL LIMNOLOGY. (4 cr; prereq 5601 or EEB 5601) Shapiro
Tectonic and climatic setting of lakes; physical, chemical, and biological processes of sedimentation in lakes.

5611s. GROUNDWATER GEOLOGY. (4 cr; prereq 1001 or 3202, Chem 1051, Math 1261, Phys 1251 or #) Pfannkuch
Origin, occurrence, and movement of groundwater viewed in the context of the hydrologic cycle. Characteristics of aquifer systems. Exploratory investigations. Hydrogeologic units and boundaries of regional systems. Analysis of surface water and groundwater interaction, recharge. Quality and chemistry of groundwater supplies.

5613f. TRACERS IN HYDROGEOLOGY. (3 cr; prereq 5611, #; offered 1993 and alt yrs) Alexander, Pfannkuch
Review of the use of tracers in hydrogeology to determine the source, age, and mixing parameters of water in various natural reservoirs.

5615. PETROLEUM RESERVOIR GEOLOGY. (2 cr; prereq 1001 or #) Kleinspehn, Pfannkuch
Introduction to subsurface geology and its application evaluating petroleum and natural gas reservoirs.

5621. LIMNOLOGY LABORATORY. (2 cr, §EEB 5621; prereq 5601 or EEB 5601 or #) Shapiro
Laboratory 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.

5631. EARTH-SYSTEM SCIENCE. (4 cr; prereq 3201, 3202, 3301) Kelts
Integrated study of global aspects of the oceanic, atmospheric, and tectonic systems.

5651. SEDIMENTOLOGY. (5 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.

5652w. SEDIMENTARY PETROLOGY AND PROCESSES. (5 cr; prereq 3402, 5651 or #; offered 1994 and 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.

5653. STRATIGRAPHY AND BASIN ANALYSIS. (4 cr [6 cr with lab]; prereq 5651 or #; offered 1993 and 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.

5654. MARINE SEDIMENTARY ENVIRONMENTS. (4 cr; prereq 5651 or #; offered 1994 and alt yrs) Kleinspehn
Principles of facies analysis of modern and ancient marine depositional systems.

5655. CONTINENTAL SEDIMENTARY ENVIRONMENTS. (4 cr; prereq 5651 or #; offered 1993 and alt yrs) Kleinspehn
Principles of facies analysis of modern and ancient nonmarine depositional systems.

5656. DEPOSITIONAL MECHANICS. (3-4 cr; prereq 5651, Math 3261 or #; offered 1993 and alt yrs) Paola
Elementary mechanics of sediment transport applied to quantitative interpretation of sedimentary rocks.

5980. SEMINAR: CURRENT TOPICS IN GEOLOGY AND GEOPHYSICS. (1-6 cr; prereq #)

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

8098. SEMINAR: CURRENT TOPICS IN GEOLOGY AND GEOPHYSICS

8099. RESEARCH IN GEOLOGY AND GEOPHYSICS

8202. ADVANCED STRUCTURAL GEOLOGY

8203. GEOTECTONICS

8262. QUATERNARY PALEOECOLOGY AND CLIMATE

8315. STABLE ISOTOPE GEOCHEMISTRY

8453. PHASE EQUILIBRIA IN MINERAL SYSTEMS

8454. IGNEOUS PETROLOGY

8455. METAMORPHIC PETROLOGY

8602. ADVANCED LIMNOLOGY

8612. ANALYTICAL GEOHYDROLOGY

8617. TRANSPORT PHENOMENA IN NATURAL POROUS MEDIA

8621. TRACERS IN HYDROGEOLOGY

Geophysics

8521. LINEAR DATA PROCESSING WITH GEOPHYSICAL APPLICATIONS

8543. PRINCIPLES OF ROCK MAGNETISM

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).

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.

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.

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.

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.

3331. TECHNOLOGY AND AMERICAN CULTURE. (4 cr, §5331) 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.

3332. SCIENCE AND AMERICAN CULTURE. (4 cr, §5332) Kolhstedt
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.

3711, 3712, 3713. TECHNOLOGY AND WESTERN CIVILIZATION. (4 cr per qtr, §1711, §1712, §1713)
For description, see 1711, 1712, 1713.

3811, 3812, 3813. INTRODUCTION TO HISTORY OF SCIENCE. (4 cr per qtr, §1811, §1812, §1813)
For description, see 1811, 1812, 1813.

3825. 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.

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.

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.

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.

5201, 5202. HISTORY OF BIOLOGY. (4 cr per qtr, §3201, §3202)
For description, see 3201, 3202.

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.

5321. HISTORY OF COMPUTING. (4 cr) Norberg
For description, see 3321.

5331. TECHNOLOGY AND AMERICAN CULTURE. (4 cr, §3331) Norberg
For description, see 3331.

5332. SCIENCE AND AMERICAN CULTURE. (4 cr, §3332) Kohlstedt
For description, see 3332.

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.

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.

5825. THE NUCLEAR AGE. (4 cr, §3825) Stuewer
For description, see 3825.

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.

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.

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.

5970. DIRECTED STUDIES. (1-15 cr per qtr; prereq #) Guided individual reading or study.

5990. DIRECTED RESEARCH. (1-15 cr per qtr; prereq #)

For Graduate Students Only

(For description, see *Graduate School Bulletin*)

8111. HISTORIOGRAPHY OF HISTORY OF SCIENCE AND TECHNOLOGY

8121. FOUNDATIONS FOR RESEARCH IN ANCIENT SCIENCE

8122. FOUNDATIONS FOR RESEARCH IN THE SCIENTIFIC REVOLUTION

8900. SEMINAR: HISTORY OF EARLY PHYSICAL SCIENCES

8910. SEMINAR: HISTORY OF MODERN PHYSICAL SCIENCES

8920. SEMINAR: HISTORY OF BIOLOGICAL SCIENCES

8930. SEMINAR: HISTORY OF TECHNOLOGY

8940. SEMINAR: HISTORY OF SCIENCE AND TECHNOLOGY IN AMERICA

8941. WOMEN IN SCIENCE: HISTORICAL PERSPECTIVES

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.

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.

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.

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.

5030. QUALITY CONTROL AND RELIABILITY. (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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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*)

8110-8111-8112. ADVANCED INDUSTRIAL ENGINEERING

8310-8311-8312. PRODUCTION ENGINEERING PROBLEMS

8410-8411-8412. INDUSTRIAL ENGINEERING RESEARCH

8420. LINEAR PROGRAMMING

8430. NONLINEAR PROGRAMMING

8440. DYNAMIC PROGRAMMING

8450. QUEUING THEORY

8460. STOCHASTIC PROGRAMMING

8470. ADVANCED INVENTORY AND PRODUCTION CONTROL

8480. HUMAN-MACHINE SYSTEMS

8773-8774-8775. GRADUATE SEMINAR

Materials Science and Engineering (MatS)

Note: Course numbers and descriptions subject to change. Check with department in 151 Amundson Hall.

3090, 3091, 3092. INDUSTRIAL EMPLOYMENT. (1-2 cr per qtr [depending on duration of employment])
Employment with industrial firms that perform metallurgical or materials engineering activities. Report covering work required.

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 laboratory/recitation with emphasis on engineering alloys and heat treatment.

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.

5011. INTRODUCTION TO THE SCIENCE OF MATERIALS. (4 cr; prereq upper div ChEn or MatS major, Chem 5533 or #; 3 hrs lect, 2 rec hrs per wk)
General introduction to materials. Metals, polymers, ceramics, glasses, composites, electrical and magnetic materials.

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.

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.

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.

5102. DIFFUSION AND SOLID STATE KINETICS. (4 cr; prereq upper div IT, 5001, 5101 or 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.

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.

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 micro-analysis for metallurgical material systems.

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.

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.

5411. MATERIALS DESIGN. (4 cr; prereq sr MatS major, 5012 or #; 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.

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.

5455. ELECTROCHEMICAL ENGINEERING. (4 cr, §ChEn 5455; prereq upper div IT or grad, 5101, 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.

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.

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.

5481, 5482, 5483. SPECIAL PROBLEMS IN PHYSICAL METALLURGY AND MATERIALS SCIENCE. (Cr and hrs ar; prereq sr standing)
Library or laboratory studies of scientific or engineering problems in physical metallurgy and materials science.

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 laboratory experience through independent study. Subject area contracted with faculty adviser of student's choice. Term paper and oral presentation required.

5610. POLYMER CHEMISTRY. (3 cr; prereq upper div IT, Chem 3301 or Chem 3331 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.

5613. POLYMER LABORATORY. (2 cr; one 4-hr lab per wk)
Students synthesize and characterize the molecular structure and properties of several polymers. Experiments include 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.

5620. PROCESSING OF POLYMERS AND THEIR COMPOSITES. (3 cr; prereq heat transfer and fluid mechanics or #; 3 lect hrs per wk)
Polymer processing principles and applications: rheology of long chain molecules, flow in simple geometries, die design, mixing, thermal properties, heat transfer, and phase change. Thermoplastic operations—extrusion, forming, and molding. Thermoset operations—fiber and particulate reinforced composite molding, pultrusion, and filament winding.

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: structure and morphology of the crystalline and amorphous state. Crystallization kinetics, vitrification and the glass transition, mechanical properties, failure, permeability, optical and electrical properties, polymer composites, effect of processing on properties.

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*)

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

8112. SOLID-STATE REACTIONS

8210. CRYSTALLINE PROPERTIES OF METALS

8213, 8214. ELECTRONIC PROPERTIES OF MATERIALS

8311. THEORIES OF MECHANICAL BEHAVIOR OF SOLIDS

8320. HIGH-TEMPERATURE PROPERTIES OF MATERIALS

8401. TRANSFORMATIONS IN ALLOYS AND ORIGINS OF MICROSTRUCTURE

8460. OXIDATION OF METALS

8470, 8471, 8472. SEMINAR: MATERIALS SCIENCE AND ENGINEERING

8480, 8481, 8482. SELECTED TOPICS IN MATERIALS SCIENCE AND ENGINEERING

8520. ELECTRON DIFFRACTION AND ELECTRON MICROSCOPY

8521. TOPICS IN ELECTRON MICROSCOPY

8522. ADVANCED X-RAY DIFFRACTION OF METALS

Mathematics (Math)

1001. EXCURSIONS IN MATHEMATICS. (See *College of Liberal Arts Bulletin*)

1005-1006. INTRODUCTION TO ELEMENTARY MATHEMATICS. (See *College of Liberal Arts Bulletin*)

1008. TRIGONOMETRY. (See *College of Liberal Arts Bulletin*)

1031. COLLEGE ALGEBRA AND PROBABILITY. (*See College of Liberal Arts Bulletin*)

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.

1131. FINITE MATHEMATICS. (See *College of Liberal Arts Bulletin*)

1142. SHORT CALCULUS. (See *College of Liberal Arts Bulletin*)

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.

1171-1181-1191. PRECALCULUS AND INTRODUCTION TO HIGHER-LEVEL MATHEMATICAL PATTERNS. (See *College of Liberal Arts Bulletin*)

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.

1261. ALGEBRA AND GEOMETRY OF EUCLIDEAN SPACE. (4 cr, §1241, §3142, §1553H, §3511H; prereq 1211 or 1251)
Vectors and their operations; matrices and matrix algebra, linear algebraic equations; Gaussian elimination; determinants and their applications; linear transformations; subspaces, quadratic functions, rigid motions, orthogonal matrices.

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.

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: vector geometry and linear algebra (1553H); ordinary differential equations (3551H); multivariable differential calculus (3551H-3552H); multivariable integral calculus (3552H); Taking courses in consecutive quarters recommended.

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.

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.

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.

3251. MULTIVARIABLE DIFFERENTIAL CALCULUS. (4 cr, §3211, §3311, §3521H, §3552H; prereq 1251, 1261)
Differentiation of parametric curves; partial differentiation and the derivative as local linear approximation; the chain rule; applications to max/min problems with attention to boundaries and constraints, including Lagrange multipliers; Taylor's Theorem (multivariable) and the second derivative test.

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.

3261. DIFFERENTIAL EQUATIONS WITH LINEAR ALGEBRA. (4 cr, §3221, §3321, §3531H, §3551H; prereq 1221 or 1252, 1241 or 1261 or 3142)
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.

3262. INFINITE SEQUENCES AND SERIES WITH METHODS OF APPROXIMATION. (4 cr; prereq 3261 or ¶3261)
Infinite sequences and series; mathematical induction and its implications for recursively defined sequences; convergence and techniques for evaluation of sequential limits and sums of series; applications of sequences and series to approximations and estimates of error. Required for mathematics honors students who have not taken Math 1552H.

3511H. HONORS: LINEAR ANALYSIS. (5 cr, §1261; prereq 1731H)
Continuation of 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.

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.

3551H-3552H. HONORS: LINEAR AND NONLINEAR ANALYSIS II-III.
See 1553H.

5005. THE DIVERSITY OF MATHEMATICS. (4 cr; prereq 1005-1006 or equiv, 10 cr college-level math courses, elementary education majors only; no credit for others)
Mathematics enrichment topics for elementary school instructors: number theory, including prime numbers and congruences; various topics involving fractions and decimals.

5006. THE DIVERSITY OF MATHEMATICS. (4 cr; prereq 1005-1006 or equiv, 10 cr college-level math courses, elementary education majors only; no credit for others)
Mathematics enrichment topics for elementary school instructors: polyhedra, map coloring, analytic geometry, finite arithmetics and geometries, projective geometry.

5007. THE DIVERSITY OF MATHEMATICS. (4 cr; prereq 1005-1006 or equiv, 10 cr college-level math courses, elementary education majors only; no credit for others)
Mathematics enrichment topics for elementary school instructors: the theory of area, probability, mathematical games, combinatorics, and graph theory.

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.

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.

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.

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.

5162-5163-5164. MATHEMATICAL LOGIC. (4 cr per qtr; prereq 1 yr of 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.

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.

5232-5233. COMPUTER-ORIENTED LINEAR ALGEBRA. (4 cr per qtr, §5242-5243, §5247, §5284; prereq 1261, 3142 or 3261 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.

5242-5243. LINEAR ALGEBRA WITH APPLICATIONS. (4 cr per qtr, §5232-5233, §5247, §5284; prereq 1261, 3142 or 3261 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.

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.

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.

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.

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.

5343. INTRODUCTION TO ALGEBRAIC TOPOLOGY. (4 cr; prereq 5342)
Classification of two-manifolds, fundamental group, homology theory.

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.

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.

5428. MATHEMATICAL MODELS IN ECONOMICS AND THE SOCIAL, ACTUARIAL, AND MANAGEMENT SCIENCES. (4 cr; prereq 3261 or equiv or #)
Mathematical models and associated mathematical techniques for analyzing various systems and the solutions of certain problems. Examples from Markov processes, linear programming, queuing theory, spread of epidemics.

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.

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.

5463-5464-5465. THE MATHEMATICS OF INDUSTRIAL PROBLEMS. (4 cr; prereq 2 yrs of calculus including ¶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.

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.

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.

5512-5513. DIFFERENTIAL EQUATIONS WITH APPLICATIONS I-II. (4 cr per qtr; prereq 3261 or equiv or #; 3262 recommended)
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.

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.

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.

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.

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.

5568. ELEMENTARY THEORY OF COMPLEX VARIABLES. (4 cr, §3541, §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.

5569. OPERATIONAL MATHEMATICS. (4 cr, §5573; prereq 5568)
Laplace transforms, Fourier transforms, inversion theorems; applications to differential equations.

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.

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. Analysis on the line (5606-5607) and in Euclidean space (5608). Other topics at instructor's discretion.

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.

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.

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.

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.

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.

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.

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*)

8140-8141-8142. APPLIED LOGIC

8166-8167-8168. RECURSION THEORY

8190-8191-8192. TOPICS IN LOGIC

8200-8201-8202. GENERAL ALGEBRA

8203-8204-8205. ALGEBRAIC GEOMETRY

8206-8207-8208. ALGEBRAIC NUMBER THEORY

8209-9210. HOMOLOGICAL ALGEBRA

8211-8212. COMMUTATIVE ALGEBRA

8250-8251-8252. TOPICS IN GROUP THEORY

8263-8264-8265. TOPICS IN ALGEBRAIC GEOMETRY

8266-8267-8268. TOPICS IN NUMBER THEORY

8270-8271-8272. LIE GROUPS AND LIE ALGEBRAS

8290-8291-8292. TOPICS IN ALGEBRA

8300-8301-8302. MANIFOLDS/TOPOLOGY

8306-8307-8308. ALGEBRAIC TOPOLOGY

8330-8331-8332. DIFFERENTIAL TOPOLOGY

8342-8343-8344. TOPOLOGICAL DYNAMICS

8360-8361-8362. TOPICS IN TOPOLOGY

8365-8366-8367. RIEMANNIAN GEOMETRY

8370-8371-8372. TOPICS IN GEOMETRY

8380-8381-8382. TOPICS IN ADVANCED DIFFERENTIAL GEOMETRY

8406-8407-8408. ADVANCED METHODS OF APPLIED MATHEMATICS

8430-8431-8432. MATHEMATICAL THEORY OF FLUID DYNAMICS

8445-8446-8447. NUMERICAL ANALYSIS OF ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS

8450-8451-8452. TOPICS IN NUMERICAL ANALYSIS

8460-8461-8462. MATHEMATICAL PROBLEMS IN THEORETICAL PHYSICS

8480-8481-8482. SELECTED TOPICS OF CELESTIAL MECHANICS

8500-8501-8502. THEORY OF ORDINARY DIFFERENTIAL EQUATIONS

8540. TOPICS IN DIFFERENTIAL AND DIFFERENCE EQUATIONS

8550-8551-8552. THEORY OF PARTIAL DIFFERENTIAL EQUATIONS

8560-8561-8562. CALCULUS OF VARIATIONS AND MINIMAL SURFACES

8570-8571-8572. INFINITE DIMENSIONAL DYNAMICAL SYSTEMS

8590-8591-8592. TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS

8600-8601-8602. REAL ANALYSIS

8620-8621-8622. THEORY OF SINGULAR INTEGRALS

8640-8641-8642. TOPICS IN REAL ANALYSIS

8650-8651-8652. THEORY OF PROBABILITY

8653-8654. INTRODUCTION TO STOCHASTIC PROCESSES

8656-8657-8658. MEASURE THEORY AND PROBABILITY

8668-8669-8670. INTRODUCTION TO COMBINATORIAL THEORY

8672, 8673, 8674. TOPICS IN COMBINATIONAL THEORY

8690-8691-8692. TOPICS IN THE THEORY OF PROBABILITY

8700-8701-8702. COMPLEX ANALYSIS

8790-8791-8792. TOPICS IN THE THEORY OF ANALYTIC FUNCTIONS

8800-8801-8802. FUNCTIONAL ANALYSIS

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, for more information.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

5195. MECHANICAL ENGINEERING DESIGN ANALYSIS. (3 cr; prereq ME or EE major or grad, EE 5451-5452, # permission of student's major dept)
Application of mathematical and computational techniques to design problems chosen from wide range of engineering disciplines. Frequent use made of interdisciplinary problems first encountered in industry. Elasticity, fluid mechanics, thermodynamics, one-dimensional compressible flow, and heat transfer. Weekly written reports required.

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.

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.

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.

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.

5220. COMPUTER-AIDED DESIGN. (4 cr; prereq IT or grad student, 3020; 3rd-yr ME courses; 3 lect, 1 rec hrs per wk)
Application of computer-aided design techniques to engineering design. Engineering design projects/case studies using selected computerized numerical techniques, design optimization, and computer graphical presentation of results.

5221. COMPUTER GRAPHICS IN DESIGN. (4 cr; prereq IT or grad student, 5220 or #; 3 lect, 2 lab hrs per wk)
Introduction to software techniques and hardware for applications of computer graphics to mechanical engineering design. Modeling and analysis of systems using graphical techniques to enhance human-machine interaction.

5225. FINITE ELEMENTS IN MECHANICAL DESIGN. (4 cr; prereq IT or grad student, 3205, 5342, programming)
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.

5226. FINITE ELEMENT METHODS IN MECHANICAL ENGINEERING I. (4 cr; prereq upper div IT or grad student, 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.

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.

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.

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.

5232. FLUID POWER CONTROL LABORATORY. (2 cr; prereq upper div ME, 3201, 3701, 3702, AEM 3200)
Selection of components for fluid power systems; closed-loop control system design for force, velocity, and position control; performance prediction and testing techniques.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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. Laboratory projects.

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. Laboratory projects.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

5402. ECOLOGY, TECHNOLOGY, AND SOCIETY. (4 cr, §ID 5402; prereq IT or grad student; 4 lect hrs per wk)
Dilemmas produced as a result of conflicts between finite limits and population and industrial growth; underlying causes: current technology, values, economics, institutions, and political structures; and possible directions for resolution. Faculty members from various disciplines participate.

5403. ECOLOGY, TECHNOLOGY, AND SOCIETY. (4 cr, §ID 5403; prereq 5402, IT or grad student; 3 lect hrs per wk)
Military technology related to problems of life support, major dilemmas of economic growth and control of technology, ethical problems faced by engineers, factors in transition to sustainable society.

5430. INTERNAL COMBUSTION ENGINE PERFORMANCE LABORATORY. (2 cr; prereq upper div ME, 3701, 3702, 5460, AEM 3200 or CE 3400)
Performance and emissions from both gasoline and diesel internal combustion engines are measured for a range of engine operating conditions.

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.

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.

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.

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.

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.

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.

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.

5461. ADVANCED INTERNAL COMBUSTION ENGINES. (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.

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.

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)
Introduction to rheology and fluid dynamics of biological fluids. Blood flow, biological pumping, self-propelled particles, unusual viscoelastic behavior of biological fluids, and other fluid motions.

5603. THERMAL ENVIRONMENTAL ENGINEERING. (4 cr; prereq 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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*)

8190. MECHANICAL ENGINEERING GRADUATE SEMINAR

8203. ADVANCED PLANAR LINKAGE SYNTHESIS

8210. ADVANCED VIBRATION ENGINEERING

8211-8212-8213. APPLIED DYNAMICS

8221. ADVANCED COMPUTER GRAPHICS TOPICS

8225. FINITE ELEMENT ANALYSIS

8226. FINITE ELEMENT METHODS FOR NONLINEAR/LINEAR TRANSIENT DYNAMIC PROBLEMS

8227. THE FINITE ELEMENT METHOD IN METAL FORMING PROCESSES

8243. PHOTOELASTICITY

8280. MULTIVARIABLE CONTROL SYSTEMS I

8281. MULTIVARIABLE CONTROL SYSTEMS II

8310. ADVANCED THERMODYNAMICS

8311. STATISTICAL AND NONEQUILIBRIUM THERMODYNAMICS

8326. BOILING HEAT TRANSFER AND MULTIPHASE FLOW

8330. CONDUCTION

8331. CONVECTION

8332. RADIATION

8333. ADVANCED THEORY OF HEAT TRANSFER

8334. TURBULENT CONVECTION

8350. ADVANCED FLUID THERMODYNAMICS

8351. COMPUTATION OF FLUID FLOW AND HEAT TRANSFER

8352. ADVANCED COMPUTATION OF FLUID FLOW AND HEAT TRANSFER

8353. COMPUTATION OF BOUNDARY LAYER FLOWS

8360-8361-8362. INTRODUCTION TO PLASMA TECHNOLOGY

8370. EXPERIMENTAL METHODS IN HEAT TRANSFER

8372. OPTICAL DIAGNOSTICS OF FLOW SYSTEMS

8442. ADVANCED POWER PLANTS

8443. APPLIED THERMODYNAMICS I

8444. APPLIED THERMODYNAMICS II

8445. APPLIED THERMODYNAMICS III

8446. ENERGY TRANSPORT IN CHEMICALLY REACTING GASES

8447. MASS TRANSFER IN CHEMICALLY REACTING GASES

8448. ATOMIZATION, VAPORIZATION, AND MIXING

8450. DYNAMICS OF HIGH SPEED ENGINES

8453. ADVANCED GAS TURBINES AND JET PROPULSION

8455. ADVANCED ROCKET PROPULSION

8613. FUNDAMENTALS OF AEROSOL BEHAVIOR

8701-8702. DESIGN STUDIES IN ENGINEERING I-II

8770-8771-8772. MECHANICAL ENGINEERING RESEARCH

8773-8774-8775. GRADUATE SEMINAR

8800. MODERN DEVELOPMENT IN MECHANICAL ENGINEERING

Physics (Phys)

1001f,w,s. 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.

1005f,w,s. PHYSICS LABORATORY. (1 cr [no cr for IT students]; prereq 1001 or ¶1001; 2 lab hrs per wk)
Laboratory experiments offered in conjunction with 1001.

1041f,w,su,CEE-1042w,s,su,CEE. INTRODUCTORY PHYSICS. (5 cr per qtr; prereq high school algebra and plane geometry; 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.

1104f-1105w-1106s. GENERAL PHYSICS. (4 cr per qtr [no cr for IT students]; prereq Math 1142, high school trigonometry or Math 1008 for 1104; 4 lect, 1 rec 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: Conservation principles. 1106: Selected topics with applications in biology. Concurrent lab required (1107-1108-1109 for 1993-94).

1107f-1108w-1109s. GENERAL PHYSICS LABORATORY. (1 cr per qtr [no cr for IT students]; prereq 1104-1105-1106 or ¶1104-1105-1106; 2 lab hrs per wk)
Laboratory exercises.

1251f,w,su,-1252w,s,su,-1253f,s,su,-1254f,w (formerly 1271-1281-1291 and 1275-1285-1295, also 1311-1321-1331-1341). GENERAL PHYSICS I-IV. (4 cr per qtr, §1271-1281-1291, §1311-1321-1331-1341, §1411H-1421H-1431H-1441H or §1451H-1452H-1453H-1454H; prereq Math 1251 or ¶Math 1251 for 1251, Math 1252 or ¶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 and waves. 1253: Electricity and magnetism. 1254: Thermal and statistical physics and the atomic structure of matter.

1451Hf-1452Hw-1453Hs-1454Hf (formerly 1411H-1421H-1431H-1441H). HONORS PHYSICS I-IV. (4 cr per qtr, §1251-1252-1253-1254, §1271-1281-1291, §1311-1321-1331-1341 or §1411H-1421H-1431H-1441H; 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.

1911-1912. LABORATORY-BASED PHYSICS FOR TEACHERS. (4 cr per qtr [no cr for IT students]; 6 lab hrs per wk)
Laboratory-based introductory physics course. 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.

3501. MODERN PHYSICS. (4 cr [no cr for physics majors], §3512-3513; prereq 1106 or 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.

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.

3515w,3516s. MODERN PHYSICS LABORATORY. (2 cr; prereq 3512 or ¶3512 or 3501 or ¶3501; 1 lect, 3 lab hrs per wk)
Laboratory 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.

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.

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.

5023s-5024f. INTRODUCTION TO ELECTIC 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.

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.

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.

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 laboratory at scientific computer workstation.

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.

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, collision theory.

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.

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.

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 laboratories.

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.

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.

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.

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.

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.

5231f-5232w-5233s. INTRODUCTION TO SOLID-STATE PHYSICS. (4 cr per qtr; prereq grad or advanced undergrad in 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 behaviors and magnetism. Other possible topics include superconductivity, ferroelectricity, optical phenomena, surface and interface properties, and departures from crystalline order.

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.

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.

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.

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)
Cosmic rays: characteristics, motion in interplanetary and interstellar medium. Topics in X-ray and radio astronomy.

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.

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.

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). Graphical analysis. Statistical physics (entropy, reversibility, Boltzmann factor and Nernst equation, Brownian movement, free energy). Diffusion, bulk flow, and osmosis.

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).

5553s. TOPICS IN PHYSICS FOR BIOLOGY AND MEDICINE: LIGHT, ATOMS, AND NUCLEI. (5 cr per qtr; prereq general physics, calculus; offered alt yrs)
Atoms (dispersion, absorption, spectra, polarized light). X-rays (production, absorption, dosimetry). Nuclei (nuclear size, mass, decay).

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.

5805w. CONTEMPORARY OPTICS. (4 cr; prereq #; 4 lect hrs per wk)
Current developments in optics. Theory of lasers and their applications in holography, nonlinear optics, etc. Nonlinear optics. Optics of anisotropic media. Theory of image formation and spatial filtering. Properties of optical detectors.

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.

5924f. 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.

5925w. 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.

5940su,CEE. PHYSICS FOR HIGH SCHOOL TEACHERS: EXPERIMENTAL FOUNDATIONS AND HISTORICAL PERSPECTIVES—DIRECTED PROJECT. (2-4 cr per qtr [may be repeated for cr; no cr for physics grad or grad physics minor]; prereq completion of summer session 5940)
Continuation of summer session Phys 5940. Teachers work on assignments arising from Phys 5940 to incorporate the historical-investigative method into their classroom teaching curriculum. A major portion of the work is creating a new investigative lab and implementing it in the classroom.

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.

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.

5970. DIRECTED STUDIES. (1-5 cr; prereq #, Δ)
Independent, directed study in physics in areas arranged by the student and a faculty member.

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.

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*)

8081-8082. GENERAL RELATIVITY

8121. ADVANCED QUANTUM MECHANICS

8122. RELATIVISTIC QUANTUM MECHANICS

8123. RELATIVISTIC QUANTUM FIELD THEORY

8131. SYMMETRY AND ITS APPLICATIONS TO PHYSICAL PROBLEMS

8161. ATOMIC AND MOLECULAR STRUCTURE

8163-8164. PLASMA PHYSICS

8165. ADVANCED TOPICS IN PLASMA PHYSICS

8200. SEMINAR: CONDENSED MATTER PHYSICS

8211. EQUILIBRIUM STATISTICAL MECHANICS

8212. TRANSPORT THEORY

8216. MANY-BODY THEORY

8221-8222-8223. SOLID-STATE PHYSICS

8232. MAGNETISM

8233. SUPERCONDUCTIVITY

8234. TECHNIQUES OF LOW-TEMPERATURE PHYSICS

8235. LIQUID AND SOLID HELIUM

8238. ADVANCED TOPICS IN SOLID-STATE AND LOW-TEMPERATURE PHYSICS

8300. SEMINAR: NUCLEAR PHYSICS

8311. NUCLEAR STRUCTURE

8312. NUCLEAR REACTIONS

8313. RELATIVISTIC NUCLEAR MANY-BODY THEORY

8321. ADVANCED TOPICS IN NUCLEAR PHYSICS

8360. SEMINAR: MASS SPECTROSCOPY

8370. SEMINAR: ELEMENTARY PARTICLE PHYSICS

8371-8372-8373. ELEMENTARY PARTICLE PHYSICS

8380. ADVANCED TOPICS IN ELEMENTARY PARTICLE PHYSICS

8381-8382-8383. MODERN QUANTUM FIELD THEORY AND ITS APPLICATIONS

8400. SEMINAR: SPACE PHYSICS

8411-8412. COSMIC RAY AND SPACE PHYSICS

8421-8422. SOLAR AND MAGNETOSPHERIC PHYSICS

8500. PLAN B PROJECT

8950. SEMINAR: PROBLEMS OF PHYSICS TEACHING AND HIGHER EDUCATION

8990. RESEARCH IN PHYSICS

Statistics (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.

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.

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.

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.

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.

5121f-5122w. THEORY OF STATISTICS. (5 cr per qtr, §5131-5132-5133; prereq Math 1261)
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.

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.

5161-5162-5163f,w,s. APPLIED STATISTICAL METHODS. (4 cr per qtr, §5201, §5301, §5302, §5421; prereq ¶5131, admission to grad study in statistics or #)
5161: Sampling methodology. Estimation from sample surveys. Simple and multiple regression. Use of statistical packages.
5162: Advanced topics in linear regression. Nonlinear models. Generalized linear models. Categorical data analysis. Logistic regression.
5163: Variance reduction designs for experiments. Factorial, fractional, and confounded designs. Optimal designs. Analysis of covariance. Unbalanced data analysis.

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.

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.

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.

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.

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.

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.

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.

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.

5900. TUTORIAL COURSE. (Cr ar; prereq #)
Study in areas not covered by regular offerings. Directed study.

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*)

8151-8152-8153. MATHEMATICAL STATISTICS

8162. COMPUTATIONAL STATISTICAL METHODS

8171-8172-8173. THEORY OF INFERENCE

8191-8192. LARGE-SAMPLE THEORY

8221. TOPICS IN SAMPLING

8311-8312. LINEAR MODELS

8313. TOPICS IN EXPERIMENTAL DESIGN

8321. LINEAR AND NONLINEAR REGRESSION

8331. STATISTICAL COMPUTING

8401. TOPICS IN MULTIVARIATE METHODS

8411-8412. MULTIVARIATE ANALYSIS

8431. THEORY OF CATEGORICAL DATA ANALYSIS

8501-8502. INTRODUCTION TO STOCHASTIC PROCESSES WITH APPLICATIONS

8511-8512. TIME SERIES ANALYSIS

8601. TOPICS IN ROBUST METHODS

8611-8612. NONPARAMETRIC INFERENCE

8731-8732. STATISTICAL DECISION THEORY

8751-8752. SEQUENTIAL ANALYSIS

8801. STATISTICAL CONSULTING

8900. STUDENT SEMINAR

8901. DIRECTED READINGS AND RESEARCH

8931-8932-8933-8934. ADVANCED TOPICS IN STATISTICS

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Administration and Faculty

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William E. Hogan II, Minnetonka
Jean B. Keffeler, Minneapolis
H. Bryan Neel III, Rochester
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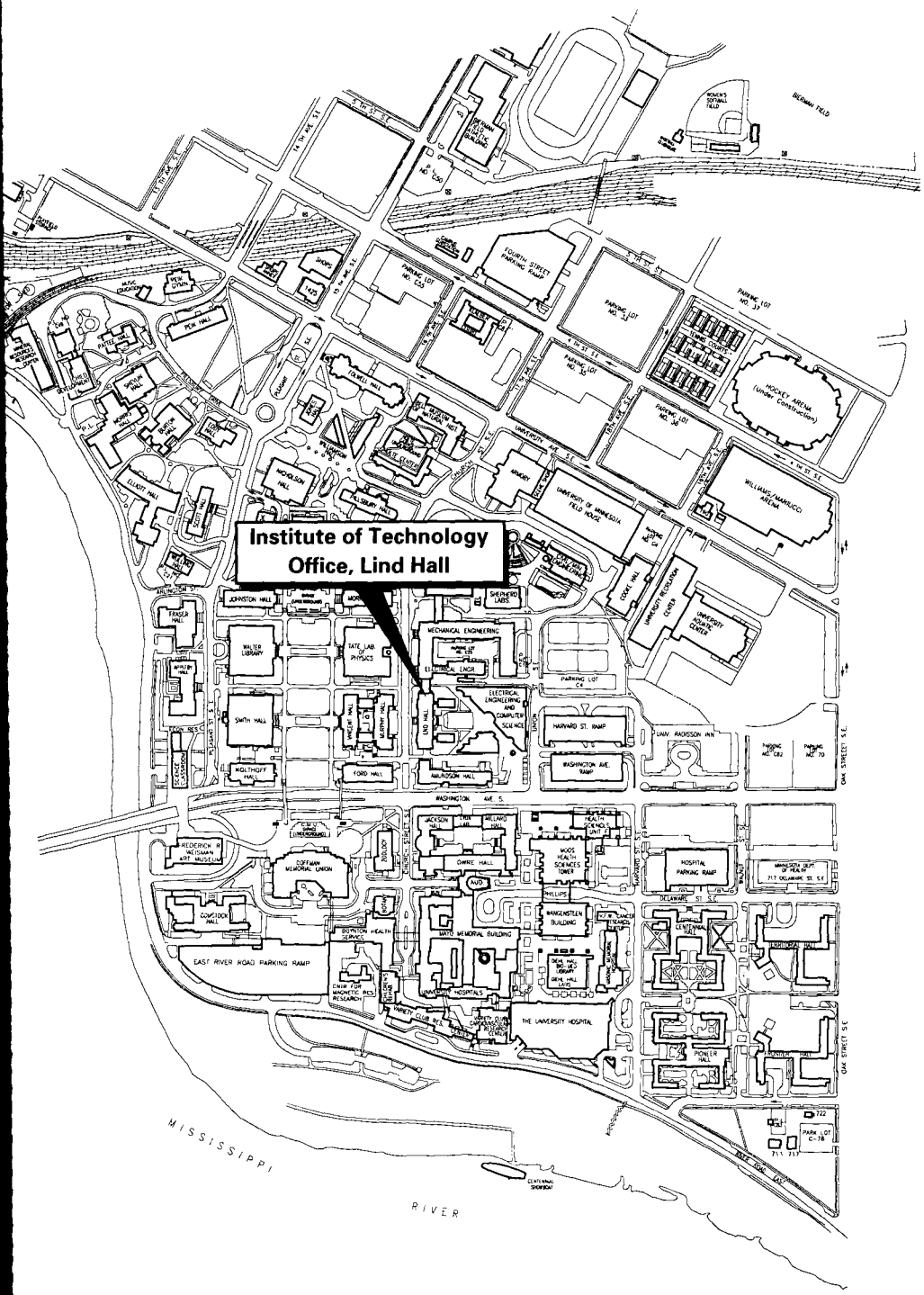
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