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HOW TO USE THIS BULLETIN

I. GENERAL INFORMATION

The general section applies to everyone. Familiarize yourself with what it covers: objectives and organization of the Institute of Technology, curricula offered, and degrees conferred; admission requirements (including Upper Division), registration procedure, types of academic work, academic standards and cancellation of courses; graduate programs; student personnel services, student activities, employment and financial assistance.

II. GENERAL CURRICULAR REQUIREMENTS

General curricular requirements, the elective groups, and the general elective requirements are discussed.

III. CURRICULA

Master what applies to you in the detailed requirements given in this section for each degree offered by the institute. Note particularly the curricula during the first 2 years and the basic courses you must have before you can take advanced work. Try to see the whole pattern.

IV. COURSE DESCRIPTIONS

To interpret the complete information about courses in this section, refer to the conventions and symbols as listed below:

* Graduate students may prepare Plan B papers.

† To receive credit, all courses listed before dagger must be completed.

‡ A sequence course may be entered any quarter preceding double dagger.

§ No credit if credit has been received for equivalent course listed after section mark.

¶ Means "concurrent registration in."

♯ Means "consent of instructor."

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

A hyphen in a course number (4-5-6) indicates a sequence course which must be taken strictly in the order listed.

Courses numbered 200 or above are for graduate students only, except by specific permission of the dean of the Graduate School.

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

A prerequisite course listed by number only (prereq 89) is always in the same department as the course being described.

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

For other information, consult the *General Information Bulletin*, the *Class Schedule*, and the Official Daily Bulletin of the *Minnesota Daily*.

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Institute of Technology

I. GENERAL INFORMATION

General Objectives and Curricula

Organization and Objectives — The Institute of Technology (often called IT) consolidates seven related curricular units. These units and the curricula leading to the Bachelor's degree are tabulated below.

College of Engineering —

School of Mechanical and Aerospace Engineering

Aerospace Engineering and Mechanics, Mechanical Engineering

School of Mineral and Metallurgical Engineering

Geo-Engineering; Metallurgy-Materials Science; and Mineral Resources Engineering (Mining and Petroleum Engineering Production Processes, Mineral and Metal Extractive Processes)

Agricultural Engineering, Civil Engineering, and Electrical Engineering

School of Architecture and Landscape Architecture —

Architecture, Landscape Architecture

School of Chemistry —

Chemical Engineering, Chemistry

School of Earth Sciences —

Geology, Options A and B; Geophysics

School of Mathematics —

Mathematics

School of Physics and Astronomy —

Physics, Astronomy

Department of Computer, Information, and Control Sciences —

Computer Science

Students enrolled in one of these may take suitable courses from the others, and from the University at large. Together they offer complete sequences of college studies or curricula.

Each curriculum is designed to prepare the student for leadership in his chosen field. To that end, the curricula first provide him with fundamental training in science and mathematics and then base on that foundation the more specialized professional courses in his selected area. The purpose is to develop in the student a thorough understanding of fundamental principles and an ability to apply that knowledge to new problems he may meet after graduation, rather than to train him only in the detailed aspects of current specialized industrial and professional practice. In addition to his professional studies the student takes a program including work in the areas of communication, man and society, and artistic expression. The final objective of each full curriculum is to produce well-balanced graduates prepared for constructive careers.

The School of Architecture and Landscape Architecture offers two 5-year curricula leading to the degrees of bachelor of architecture and bachelor of landscape architecture; also, two 6-year curricula in cooperation with the College of Liberal Arts.

Certain engineering departments, including mechanical engineering, permit specified work in industrial engineering to replace some of the optional engineering study of the fourth year and thereby provide an alternative path to the Bachelor's degree. Students petition to enter this option at the end of their third year. This option accommodates students who plan a career in engineering joined with industrial organization, scientific management, and operational research.

Engineering Intern Programs providing practical work experience in conjunction with regular classes and laboratory work are available in agricultural and mechanical engineering. These begin in the third year through cooperation with industrial concerns. During part of their collegiate program students in the intern curricula are on a 12-month basis and spend alternate quarters in industry. While on the work assignments students are paid at regular rates by the company.

The summer program of work and study in civil engineering provides tuition scholarships for selected students who complete 12 credits of study in the area of surveying and land development during the summer between their second and third years. During the summer between their third and fourth years participants in the program are assured employment under professional supervision in one of a wide variety of civil engineering offices in Minnesota. While on these work assignments students are paid at regular rates.

A combined 5-year program with the College of Education is designed to make it possible for students to qualify for the bachelor of physics degree, the bachelor of chemistry degree, or the bachelor of mathematics degree from the Institute of Technology and for the master of education degree from the College of Education. Students take courses in the two colleges concurrently during the fourth and fifth years. For the fifth year, the student transfers to the College of Education to complete his work for the two degrees, thereby satisfying the residency requirement of the College of Education. The two degrees are awarded upon completion of the 5-year program. Further information regarding this program appears in this bulletin under the departmental curricula of chemistry, mathematics, and physics, and in the *College of Education Bulletin.*

Admission Requirements

General — The undergraduate curricula of the Institute of Technology are separated into a Lower Division consisting of the first 2 years of work and an Upper Division consisting of the remaining years of work required (see section on Curricula). New freshman students are admitted to the work of the Lower Division only. Upon satisfactory completion of 96 applicable credits in the Lower Division, the student is automatically admitted to the Upper Division. These regulations apply to all Institute of Technology units except the School of Architecture and Landscape Architecture.

High School Requirements — Students wishing to enter the Institute of Technology should complete 4 years of high school mathematics and either a course in physics or chemistry. Courses in both physics and chemistry are recommended; if only one course is taken, physics is preferred. If these courses are unavailable in the student's high school, consideration should be given to available independent study courses (see *Independent Study Bulletin*) and extension classes (see *Evening Classes Bulletin*).

1. *Course Requirements*
   a. Twelve units completed in grades 10-12, including 3 years in English, 1 year in either physics or chemistry (preferably physics) and 2 or more years (total) from the following: foreign language, history, social science, and biological science.
   b. Four years of high school mathematics, divided approximately into 2 years of algebra and 2 years of geometry of two and three dimensions, including trigonometry.
   If a student lacks either a half year in algebra or a half year in geometry, or a half year in both of these subjects, he can be admitted on the condition that he make up his deficiency by the end of his first quarter in residence (without IT credit).

2. *Academic Standing*
   The primary factors considered in determining admissibility are high school class rank and achievement in the mathematics and natural science ACT tests. These factors are combined to provide an Institute of Technology aptitude rating (ITAR) as indicated below:

$$ITAR = HSR + 2\left[ACT_{Math} + ACT_{NatSci}\right]$$

The HSR is in percentile and the eleventh grade rank is used if the applicant has not yet completed the twelfth grade.

The ACT figures are the standard scores and range 0 to 36. Most, but not all, of the applicants with an ITAR of 160 or over will be admitted and most applicants with an ITAR less than 160 will be rejected. Applicants with ratings of 190 or over will be admitted without further review of the applications and transcripts — provided they meet the course requirements in item 1 above.

A student not eligible for admission directly may apply for transfer to the Institute of Technology after 1 or more years of satisfactory work in some other college, such as a local junior college, a liberal arts college, a state college, or other colleges of the University. Students who enter another college intending to transfer later to IT must consult with the counselors in that college at the very beginning of the school year in order to plan for this transfer and to receive help in planning their programs in relation to this goal. Students who intend to transfer from General College must have satisfactorily completed 1 year of an IT sequence — preferably mathematics.

New students receive their English classification on the basis of their high school grades and test information. If students are assigned to Preparatory Composition, they must complete this course during the quarter assigned. No credit is given for this course. Registration for Preparatory Composition is in 210 Johnston Hall; a fee of $21 is charged.

A student who has had high school foreign language courses cannot register for equivalent beginning courses (1, 2, 3, or 4) without taking a placement test. Forms are available in 133 Main Engineering.

A student assigned to Preparatory Composition would ordinarily be expected to complete his requirement by taking Engl 1-2-3. However, if a student makes a grade of A or B in Preparatory Composition, he may complete his English requirement by completing Engl 1-2 with a minimum grade of C. All students in IT must complete 9 credits of English requirement. In the case of exemptions from English, these credits may be satisfied with language or literature courses.

Opportunities for the Superior Student — *Advanced Placement* — High school students entering the Institute of Technology can, on the basis of exceptional background, qualify for advanced placement in one or more departments.

Entering freshmen in IT can receive advanced standing from the Department of English, and receive 6 credits toward the language-literature requirement for graduation. Advanced placement for entering freshmen is also available in chemistry, mathematics, and physics. Students desirous of such consideration should consult the chairmen of the three departments.

The University of Minnesota participates in the Advanced Placement Program of the College Entrance Examination Board. Advanced placement is available at the University in all areas in which examinations are offered.

Honors Programs and Independent Study — A wide variety of special opportunities is available to students of high ability. Honors courses are available in a number of departments at both the Lower Division and Upper Division levels. Students may petition (available in 133 Main Engineering) permission to take comprehensive examinations in courses which have been mastered through independent study; in this way, the student may enrich his educational program and accelerate his progress. Full credit for such work done outside of regular classes may be allowed by the assistant dean in IT. Comprehensive examinations are a means of enrichment for the qualified student; they cannot, in general, be used for the removal of failures. (See section on Special Examinations.)

Research Participation — Opportunities for research are available in most of the departments of the Institute of Technology. Students should consult the department chairmen for details. Usually, the student participates in one of the on-going research programs of the department. In individual instances a student may be assigned an independent project and write a report on his project. In some cases a student may, upon approval of the department, receive credit for this work.

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

Students should make application and have all transcripts on file with the Office of Admissions and Records more than a month before the beginning of the quarter in which they wish to enter. August 1 is the usual deadline for fall quarter; certain specialized programs have earlier deadlines as noted in the college bulletins.

Credit for a course in which a grade of D has been received will be allowed in technical course sequences only if it is followed by a higher grade in a course in the sequence. Grades of D in liberal education electives and English are accepted in transferring from outside the University. An advanced standing student may not repeat a course for credit for which he has already received credit by evaluation except by petition with the approval of the department concerned and the Scholastic Standards Committee.

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

Students with advanced standing will be admitted either to the Upper Division or to the Lower Division depending upon their course background at the time of admission. Students who are in the Lower Division may register for Upper Division courses provided they have the prerequisites for such courses.

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

Admission of Nonresidents — The University will receive the applications for admission of non-Minnesotans who have above-average promise, superior high school or college records, and special interest in this University. Freshman applicants are also required to take the tests of the American College Testing program. College Entrance Examination Board test scores are requested when available. Since individual consideration by the faculty concerned is usually involved, any nonresident should apply promptly, i.e., at least 2 months in advance of the desired entrance date.

Change of Major Department — A student desiring to change his major department within IT must submit a petition and a current transcript. Forms are available in 133 Main Engineering. The petition must be approved by the chairman (or his representative) of the department to which the student wishes to transfer.

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

Admission to the Upper Division — Requirements for admission to the Upper Division are as follows:

1. Satisfactory completion of at least 96 credits of work applicable to the degree sought.
2. A grade point average (GPA) of at least 2.00.
3. A student with 96 credits or more of applicable work but with a GPA of less than 2.00 will be admitted to the Upper Division if his department's Scholastic Standards Committee allows him to continue in IT.

Registration and Types of Academic Work

Registration for Credit in Regular Courses — In order to register, new students must present an admission certificate and a record of advanced standing if a transfer student. All students begin their registration in the Main Engineering Building (Room 133) and must have a registration permit. Registration instructions are furnished by the office of the assistant dean and are placed on bulletin boards in the buildings in which the IT departments are located. These instructions also appear each quarter in the Official Daily Bulletin.

A student usually takes courses in the order shown by his curriculum. The prerequisites of any course must be met unless special permission to waive the prerequisites is granted by the head (or his representative) of the department giving the course. The Waiver of Prerequisite form must be filled out in duplicate and approved. One copy is filed in 133 Main Engineering; the second copy is for the student. Any departure from the specified requirements for a degree must be approved by petition. Such a petition requires the approval of the head of the department and of the dean's office.

P-N registration must be declared at the time of first registration in a course and *may not* be changed after the first meeting of the class. Such a course may be dropped, however, in accordance with the present rules on cancellation.

P-N registration is indicated by a check in the P-N column (just to left of credit column) on the registration card.

A student should be sure to check with his major department regarding what courses he will be allowed to take on a P-N basis. The adviser's signature is required for any P-N registration.

Students who register for a course(s) on a P-N basis and are later found to not meet the requirements will have their registration in such courses canceled.

Each department makes available to its majors a list of those courses or categories of courses that it restricts to A-F registration for its majors.

Students should call at their major department offices for this list.

Program conflicts are not permitted except under very special circumstances and unless special approval has been granted by the head (or his representative) of the department concerned. The Approval of Conflict form properly filled out and approved must be filed in 133 Main Engineering.

Privilege Fee — for late registration or late payment of fees:

Through first week of classes	$ 3.00
Through second week of classes	5.00
Third week of classes and thereafter	10.00
Late change of registration	2.00

A student must have paid tuition and fees by the end of the second week of the quarter in order to have the privilege of registration at the regular time for the succeeding quarter. A student is not considered as officially registered until tuition and fees are paid. A student who has not paid his fees by the end of the sixth week of classes will not be allowed to pay without special permission from the office of the assistant dean.

Cancellation from Courses — During the first 6 weeks of classes, a student may cancel a course without failure, provided he receives the consent of his adviser and has departmental approval. A formal request must be filed to cancel a course at any time. All cancellations should be processed with Form A30A obtainable in 133 Main Engineering.

After the first 6 weeks of classes, permission to cancel without failure will be granted only with adviser approval and on petition to, and with the consent of the IT Scholastic Standards Committee and of the office of the assistant dean and only if the student is not failing at the time of official cancellation. A student who cancels officially after the sixth week of classes and is failing at the time shall receive an F. A student who leaves a class at any time without officially canceling shall receive an F.

Cancellation of back work will not be granted except in case of unusual circumstances, and only by petition in the usual manner.

During the last 2 weeks before the beginning of final examinations, cancellation is not permitted except under the most unusual circumstances.

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

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

Cancellation of courses which results in a total below 12 credits the first 6 weeks of the Fall-Winter-Spring quarters involves a partial refund of tuition.

Auditing Courses — In special cases, a course may be "audited" provided approval of the adviser is obtained. In auditing a course, the student may not participate in the activities of the class nor take the final examination, and no grade is recorded. A symbol, V, will be entered on the transcript. The total load including audits may not exceed the maximum of 19 credits.

Repeating a Course — The faculty of the Institute of Technology took the following action at the meeting of November 26, 1968.

> For courses taken in Fall Quarter, 1968, or subsequently, those in which a grade of D or F was received may be repeated, with all grades appearing on the record, but only the last grade is to be used for computing GPA for graduation purposes. This revised method of computing GPA is not to be used for honors purposes or for graduate school admission. A student who wishes to repeat a course under this regulation must file an "intent to repeat" form in 133 Main Engineering Building. This may be done at the time of regular registration or when filing a "cancel-add" slip.

Special Examinations — Two types of special examinations are available: (a) examination for proficiency, and (b) examination for credit.

Examinations for proficiency require no fee and yield no credit or grade points. If the student's work is of passing quality, a notation will be made on his record "Course X satisfied by proficiency examination." These examinations must be taken the first quarter upon entering the University.

An examination for credit (or comprehensive examination) requires a $5 fee unless taken within 6 weeks after the student enters the University. These examinations cannot, in general, be used for the removal of failures.

Final decision as to whether or not a special examination will be given will be made by the department offering the course in question.

An examination for credit will usually be assigned a grade, though the Scholastic Standards Committee may determine whether or not a grade will be assigned. If the committee directs that a grade be assigned, it will count in the grade point average.

Evening and Independent Courses — Many Institute of Technology courses are offered by the General Extension Division of the University in evening classes and by independent study. Those who are unable to attend the regular University courses may thus obtain valuable instruction after working hours or by mail. (Note that credits earned by independent study courses do not apply toward the residence requirement.)

Regularly enrolled students in residence must have the permission of the Scholastic Standards Committee to register for courses in the Department of Evening Classes or Department of Independent Study. Transfer credit is allowed for grades of D or higher but all grades will be counted in determining grade point averages. A student on exclusion status may, by petition to his Scholastic Standards Committee, enroll for credit in evening or independent study courses approved as courses that contribute directly to his academic progress. This course work may be used by the committee in its consideration of the student's readmission.

Field Trips — In some curricula, field trips are required. Students should consult the departmental programs for details.

Reserve Officers' Training Corps — Information concerning requirements, opportunities, and courses in aerospace studies, military science, and naval science is available in the *Army-Navy-Air Force ROTC Bulletin* and from the professors of aerospace studies, military science, and naval science in the Armory. See also statement under "Requirements for IT students enrolled in ROTC."

Academic Standards

Faculty Scholastic Standards Committee — The interpretation and enforcement of the faculty regulations and academic standards are lodged in committees of the faculty designated as departmental Scholastic Standards Committees and in an Institute of Technology Committee designated as the IT Scholastic Standards Committee. These committees are empowered to make exceptions to a requirement provided the exceptions work to the educational advantage of the student. Regular petition blanks are available in the office, 133 Main Engineering. When the petition form has been completed, it should be left in the college office for the appropriate action. When the departmental committee and the IT Scholastic Standards Committee have taken action, the student will be informed by mail to his local address.

Unit of Credit and Allowable Credit Load — The standard unit of credit in the University is the quarter credit or simply, the credit. A credit corresponds to 1 class period per week for 1 quarter. This class period may be a 1-hour lecture or recitation, or 2- or 3-hour class in laboratory, drawing, surveying, or computations. In any case, 1 credit usually requires about 3 actual hours of the average student's time per week for 1 quarter. One hour of recitation is assumed to require 2 hours of preparation or study. A 2-hour laboratory period may require 1 hour of outside preparation to complete the credit.

With the exception of the School of Architecture the curricula in IT have total credit requirements ranging from 191 to 204 credits. The programs detailed in this bulletin are planned on a credit load per quarter of approximately 17 credits, and on this basis indicate a minimum completion time of 4 years. Students who plan to follow this schedule should realize that it is a full-time program and does not allow for the additional load of part-time outside work. Students who must work part-time should carry a reduced credit load and will require longer than 4 years to complete the requirements for a Bachelor's degree. First quarter freshman students are generally advised to carry a course load of from 14 to 16 credits and not to take on any outside activities. The maximum load that a student may carry without special approval is 19 credits. To carry a larger load, the student must obtain the approval of the chairman of the IT Scholastic Standards Committee. Usually the approval will be noted on the admissions and records copy and the college office copy of the registration card.

Class Attendance — All students are expected to be punctual and regular in attendance at all class exercises and to do all the work of their courses. Irregularities in attendance or habitual tardiness will be sufficient reason for exclusion from class. An absence does not exempt the student from completing the work missed while he was absent.

Examinations — No students may be excused from taking the examinations in a course except under circumstances which make it impossible for the student to be present.

A student who has been absent from an examination and who does not present an acceptable excuse to the instructor for the absence before the grades are reported will be given a mark of "0" in the examination in computing his final grade for the course. The instructor may give the student an examination at a later date upon presentation of acceptable evidence of extenuating circumstances such as illness or family emergency.

Grading System — A grade point average of 2.00 is required for graduation in the Institute of Technology.

1. There shall be five permanent grades, A (highest), B, C, D (lowest), and P (pass), which shall be acceptable for the completion of a single course.

2. There shall be two permanent grades, F (failure) and N (no credit), which shall be appropriate when a student does not complete successfully the work of a course.

3. The grades of P and N may not be used except under the provisions of a plan developed by the faculty of a particular college for applying use of these grades in certain of its courses.

4. The grades P and N shall represent a self-contained grading scale alternative to the traditional scale. For a single student in a single course, neither P nor N may be used in conjunction with A, B, C, D, or F.

5. The student seeking the Bachelor's degree at the University must earn a minimum of 75 percent of the residence course credits he offers for graduation in courses in which he has been graded A, B, C, or D.

6. Instructors should consider the line dividing the P and N grades to be at approximately the same level of performance as that dividing the D and F grades.

7. The effects of authorization of use of the P-N grading on educational practice at the University shall be reviewed by the Senate Committee on Student Scholastic Standing and the Senate Committee on Educational Policy not later than the academic year 1970-71, and a recommendation brought to the Senate by these groups for continuation of this authorization for use of P-N, or for discontinuance, or for such other modifications in Senate legislation on grading as may seem advisable.

8. There shall be a temporary grade of I (incomplete) which may be assigned when there is not sufficient information immediately available to permit the assignment of a permanent grade. This would be the case if the student has not done all the work of the course or if the instructor does not know why a student, officially registered for his course, has not appeared or has left. If the instructor is able to ascer-

tain that the student has no adequate excuse or if the student attended beyond the sixth week and was failing, F or N is the appropriate grade, with the choice of F or N depending on the grading system under which the student had registered for the course.

An I which has not turned into a permanent grade or into a W (official cancellation with approval of the student's college) by the end of the sixth week of the next regular quarter of attendance shall become an F or N. (This does not apply to students in the Graduate School or to students in a Master's degree program in undergraduate colleges; their I grades remain until changed by the instructors to some other grade.) Permission to complete the work must be obtained from the instructor. He may set a makeup deadline of less than 6 weeks.

An extension of time may be permitted for removal of I grades upon recommendation of the instructor concerned and with approval of the Scholastic Committee of the college in which the student is registered. If the petition is presented after the end of the sixth week of the next quarter of residence, a restoration of the mark of I and the completion of the required work would be considered in the nature of a special examination for which the special examination fee would be required.

9. There shall be a symbol W to indicate official cancellation from a course without grade. This shall be assigned in all cases of official cancellation during the first 6 weeks of classes irrespective of the student's standing. Whether cancellation is permitted is within the authority of the student's college to determine. After 6 weeks, W shall be posted only if the student is not failing at the time of official cancellation. W is a registration symbol, not a grade, and shall be posted by the recorder on the basis of the student's registration activity as approved by the student's college.

10. A student who cancels officially or otherwise leaves a class after the sixth week of classes and is failing at the time shall receive an F or N.

11. There shall be a symbol X which may be reported on continuation courses in which a student is permitted to continue but in which a grade cannot usually be determined until the sequence is completed. The instructor shall submit a grade for each X when the student has completed the entire sequence.

12. In courses numbered 200 and higher, the permanent grade S (satisfactory) may be used to indicate satisfactory work for graduate students. In calculating grade point averages, it counts as a B.

13. There shall be a registration symbol V (visitor) to indicate registration as an auditor or visitor.

14. There shall be a symbol T (transferred) indicating credits transferred from another institution, or from one college to another within the

University when a re-evaluation is required. It shall be posted as a preceding supplement to the original grade.

15. For purposes of determining scholarship averages, grade points shall be assigned as follows:

Each credit of A	4 grade points
Each credit of B	3 grade points
Each credit of C	2 grade points
Each credit of D	1 grade point
Each credit of F	0 grade points

A student's scholastic average — or grade point average — shall be the sum of grade points divided by the sum of credits passed and failed.

16. The official grade point average shall be calculated in accordance with paragraph 15 above regardless of when grades were earned.

17. Any college or school may set special scholastic standards or other standards as a condition for registration in particular courses of study, for placing students on probation, for admission to the college or school, for promotion, for honors, for continued residence in the college or school, or for degrees, etc.

In cases where courses have been repeated and the original grade was an F or D, only the last grade and credits will be included in the grade point computation. This applies only to courses taken (for the first time) fall quarter 1968 or thereafter.

A student's scholastic average — or grade point average — shall be the sum of grade points divided by the sum of credits passed and failed.

Only credits and grade points earned while registered at the University of Minnesota and which are accepted for graduation from the Institute of Technology are used in calculating the grade point average. For determining probationary or grace quarter status, credits of incomplete are included with 0 grade points.

a. The P-N grading option may not be elected for any course by Institute of Technology students who have earned fewer than 45 credits, unless the course is offered exclusively for freshmen and on a P-N only basis.

b. Institute of Technology students on academic probation or subject to exclusion may not register for any course on a P-N grading basis.

c. A student in the Institute of Technology may take no more than 6 credits per quarter or per summer in P-N graded courses.

d. Credit in courses graded as P or N will not be included in the calculation of scholastic standing or grade point deficiency in the Institute of Technology.

e. No more than 25 percent of the total University of Minnesota residence credits presented for graduation may be taken on a P-N basis.

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

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

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

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

Certificate in Science — If students so desire, they may apply for a certificate in science upon completion of most of the course work in the Lower Division. However, a student does not need a certificate in science in order to be admitted to the Upper Division. The certificate in science is available to any regularly admitted student of the Lower Division who applies for it and who meets the following requirements:

1. He must have a minimum of 96 quarter credits
2. He must have a grade point average of not less than 1.80
3. He must have satisfactorily completed the following:
   a. The first year of the stated curriculum to which he has been admitted
   b. Math 31-32
   c. GeCh 14-15 (or its equivalent) or OrCh 61-62, 63
   d. Phys 23-23A or Phys 7-8-9

If a student transfers to the Institute of Technology with advanced standing, he must take a minimum of 45 quarter credits in residence within IT at the University of Minnesota in order to qualify for the certificate.

General Regulations

Satisfactory work is represented by a C average or better. That is, the number of grade points must be at least twice the number of course credits.

Students Admitted to IT, Fall 1968 and Thereafter — If a student's cumulative grade point average is less than 2.00 at the conclusion of any quarter, his next quarter in residence will be his "probation" quarter. During this quarter the student will not be allowed to register for the succeeding quarter unless or until he brings a release slip from his departmental Scholastic Standards Committee to 133E. If the cumulative grade point average is less than 2.00 at the conclusion of the probation quarter the student is subject to drop action and must see his departmental Scholastic Standards Committee before he is allowed to continue the next quarter.

Students on the tentative exclusion list should see their departmental Scholastic Standards Committee representative at a time specified by the department. Two copies of the appeal form (Form E-100) will be prepared by the college office in 133E in advance of the meeting. Following action of the department committee, the student will present one form at 133 Main Engineering. The department action will be considered final following a review by the associate dean. The departmental copy of the exclusion appeal will remain in the department with its action.

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

All students, regardless of admission date, are allowed to repeat courses in which a D or F grade was received and only the last grade earned will be used in computing the GPA for graduation purposes. This applies only to courses taken Fall Quarter 1968 or thereafter.

A student who is doing unsatisfactory work but who seems capable of succeeding in another program, on the basis of counseling interviews, test scores, and other information, may wish to consider transfer to another college.

Readmission of Excluded Students — An excluded student may be readmitted when the Scholastic Standards Committee is convinced that he has a reasonable chance of removing his deficiency and continuing successfully. A student shall have the right to have his application for readmission considered at least yearly. Usually, however, a student is excluded for a period of 3 quarters. At the end of that period, he is eligible to re-enter the college. He re-enters on grace and may be excluded a second time if the quality of his work has not improved sufficiently.

A student who has been excluded for low scholarship the second time shall not be readmitted except with the approval of his Scholastic Standards Committee.

A student may be discontinued for cause at any time. A discontinued student may be readmitted if and when the Scholastic Standards Committee is satisfied that the conditions which limited achievement have been changed sufficiently to permit success. Students who return to college under this provision shall be admitted on probation, and must have the Scholastic Standards Committee approval to register the quarter following.

General Extension Division work taken by a student while he is on drop status will not be allowed for degree credit in IT, unless the student has received advance approval (by petition) for such registration.

Graduate Programs

Programs of Graduate Study — Graduate study in engineering and science leading to the master of science, master of engineering in a specific field (M.C.E., M.M.E., M.Aero.E., etc.), and the doctor of philosophy degrees, may be pursued in the Graduate School. The major fields of study include aeronautics and engineering mechanics, agricultural engineering, architecture, astronomy, chemical engineering, chemistry, civil engineering, electrical engineering, fluid mechanics, geo-engineering, geology and geophysics, industrial engineering, mathematics, mechanical engineering, mechanics and materials, metallurgy-materials science, mineral resources engineering, and physics. For a complete description of graduate work in the Institute of Technology and a statement of regulations, consult the *Graduate School Bulletin.*

Master of Engineering — The faculty of the Institute of Technology has instituted a nominal 1-year program of design-oriented study beyond the B.S. degree subject to the following regulations:

Recent studies of engineering education have concluded that a year of further study beyond the customary 4-year baccalaureate is often desirable to prepare engineers for future work in design or management. A prospective student may be neither interested in nor properly prepared to undertake the preparation for research and teaching embodied in the master of science programs now offered through the Graduate School. To satisfy this additional demand, the various engineering departments offer a 1-year program, with emphasis on design methods, leading to a degree of master of engineering in a specific field (M.C.E., M.M.E., M.Aero.E., etc). The program is designed primarily for students who have already received a Bachelor's degree in the same engineering field or who have a Bachelor's degree in a related field and appropriate professional experience. A student will spend about 40 percent of the year in a major field of study, about 20 percent in a minor, and about 40 percent on a design study of significant professional content. The program is administered by departmental or other appropriate professional engineering program committees which are monitored and advised by a Professional Masters Committee appointed by and jointly responsible to the dean of the Institute of Technology and the dean of the Graduate School.

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

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

a. Interest in and aptitude for design-oriented and creative programs as evidenced by performance in undergraduate laboratory, professional, and design courses.

b. Technical reports or other evidence of performance in industrial design. Reports on undergraduate projects.

c. Performance in undergraduate curricula. Greatest weight will be placed upon Upper Division and other professionally oriented courses. Unless there is evidence to the contrary, a GPA of 2.50 or better will normally be considered acceptable for admission. In cases that do not fit the above criteria, consideration will be given to recommendations from faculty or practicing engineers.

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

Graduate Credit for Undergraduates — If at the beginning of a quarter not more than 9 undergraduate credits are lacking for graduation (taking into account required and sequence courses), an undergraduate may carry a limited amount of graduate work (approved courses numbered 100 and above) for graduate credit. Such credit is not applicable toward an undergraduate degree. Transfer of credit must be arranged by petition to the Graduate School. Credits for courses numbered 200 or over must be approved by petition at the time of registration.

With permission of the Graduate School, an undergraduate lacking not more than 6 credits toward graduation may register in the Graduate School while completing his requirements for the Bachelor's degree.

Graduate Fellowships and Assistantships — Numerous fellowships and assistantships in the Institute of Technology are open to graduates pursuing advanced degrees. Fellowships carry stipends from $1,800 to $3,500 and assistantships have stipends of $2,520 for half-time positions.

Application for fellowships and assistantships should be made to the department concerned. Information as to procedures and forms to submit may be obtained from either the Graduate School or the department.

Professional Degree — A professional degree in engineering may be conferred upon a candidate who has obtained a Bachelor's or an advanced degree from the Institute of Technology provided he has practiced his profession for at least 8 years with at least 4 of these in responsible charge of important work. The engineer degree will be granted principally in recognition of the attainment of professional engineering competence and judgment by the candidate. Application for the degree should be made to the dean of the Institute of Technology not later than October 1 preceding the June commencement at which it is to be awarded.

Upon approval by the dean of the Institute of Technology, the student must file an Application for Degree with the Office of Admissions and Records and pay a thesis examination fee.

Student Personnel Services

Faculty Adviser — Every new student is assigned a faculty adviser from the department in which he seeks his degree at the time of registration in the Institute of Technology. Students who wish to remain in an "undecided" category for 1 year will be assigned a faculty adviser by the assistant dean's office. If a student has not been assigned an adviser, he should make that fact known at his department office, and he will be given an assignment.

At the end of the first year or at the beginning of his second year, the student makes out his program of studies for the year in consultation with his adviser. Any changes in the program must also be made in consultation with the adviser and will be accepted for registration only when they have been approved by the adviser.

Professional counselors from the Student Counseling Bureau maintain regular office hours in 133 Main Engineering Building. Students with personal problems may make an appointment to see a counselor by coming to this room.

All-University Personnel Services — In addition to the counseling within the college, the University provides several specialized personnel services for the student. He may consult any of them either with or without referral from his adviser. These services are described more fully in the *General Information Bulletin.*

Institute of Technology Placement Service — This service, located in 135 Main Engineering, is available to assist the graduating senior, graduate student, or alumnus in securing employment. Assistance is also offered the undergraduate looking for summer employment. Without assuming the responsibility of finding a position for the graduate, every effort is made to help him find the opening best suited to his aptitudes, training, and interests.

Student Activities

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

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

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

Technical Commission — The Technical Commission is the executive body of the Technical Association to which all students in the Institute of Technology belong. The association enables the students to act as a unit in matters affecting the general interests of the institute and the University. The Technical Commission (composed of the presidents of the recognized departmental societies and technical fraternities, eight members elected from the institute at large during the regular spring IT elections, and a freshman representative appointed by the Technical Commission) has general supervision and responsibility for Engineers' Day (IT Week) and other student activities in the Institute of Technology.

Minnesota Technolog and Technolog Board — The *Minnesota Technolog* is the undergraduate technical magazine of the Institute of Technology. It is a monthly publication produced by the students under the direction of an editorial and business staff selected by the student body. The policies of the magazine are determined by the Technolog Board. The Technolog Board selects the editor in chief and business manager and assists them in their work. The *Minnesota Technolog* is a member of the Engineering Colleges Magazine Association, a national organization which is constantly working toward high quality in the technical magazines of our leading engineering colleges.

All-University Student Activities — For information on cultural and recreational opportunities, individual and intramural sports, and intercollegiate athletics, refer to the *General Information Bulletin.*

Scholarships, Employment Services, and Financial Assistance for Students

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

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

Undergraduate Scholarships and Awards — The following scholarships and awards are available to students in the Institute of Technology. Information regarding these and other scholarships available in competition with students of other colleges in the University may be obtained from the Official Daily Bulletin or from the Office of Student Financial Aid, after 2 quarters of attendance.

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

ALL DIVISONS

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

Babcock and Wilcox Company Scholarships: For undergraduate students in the Institute of Technology. Amount is $100-$300.

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

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

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

Hamilton Watch Award: For a graduating senior in the division of engineering who most successfully combined proficiency in his major field of study with achievements — either academic, extracurricular, or combination of both — in the social sciences or humanities.

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

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

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

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

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

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

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

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

Alfred P. Sloan Foundation Scholarships: For entering freshmen in physical science, mathematics, physics, engineering, and business administration or social science. Demonstrable leadership, community mindedness, or administrative capacity required, along with superior scholarship. Amount is $200-$750. Three awards annually renewable upon evidence of merit.

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

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

Texaco Company Scholarship: For any science student whose training will qualify him for work in the petroleum industry. At least one recipient must use the award in his senior year; other recipients must have completed 2 years of college. Amount varies.

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

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

Western Electric Fund Scholarship: For undergraduates in engineering. Award is for tuition, fees, and books. Two awards annually.

AEROSPACE ENGINEERING AND MECHANICS

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

Douglas Aircraft Scholarship: For use of senior year student in aerospace, electrical, or mechanical engineering (in this order of preference).

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

Rosemount Engineering Company Instrumentation Award: See description under Mechanical and Aerospace Engineering, School of.

AGRICULTURAL ENGINEERING

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

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

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

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

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

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

ARCHITECTURE

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

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

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

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

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

Koppers Architectural Student Design Awards: For advanced undergraduate students in the School of Architecture. Prize for excellence in building design competition, plus student scholarship aid. Amount is $500 to the student and $500 to the School of Architecture.

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

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

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

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

North Star Concrete Company University of Minnesota Scholarship: See description under All Divisions.

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

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

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

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

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

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

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

National Endowment for the Arts: Awarded to a deserving student of architecture to enable travel within the United States to areas or specific places of particular interest to him, in order to advance his knowledge in the field and broaden his understanding of excellence through first-hand observation.

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

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

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

CHEMICAL ENGINEERING and CHEMISTRY

Henry W. Dahlberg Memorial Award in Chemical Engineering: Alpha Chi Sigma Educational Foundation and family of Henry W. Dahlberg for able student in chemical engineering in his third year. Amount is $100.

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

I. M. Kolthoff Scholarship in Analytical Chemistry Fund

Monsanto Chemical Company Scholarship: For students who have completed at least 1 year toward a major in chemical engineering. Amount is $500.

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

Twin Cities Chemical and Allied Trades Association, Incorporated, Scholarship Fund: For chemistry or chemical engineering student who has completed at least 1 quarter at the University. Amount is tuition plus incidental fee.

Universal Oil Products Company Scholarships: For advanced students in chemical or petroleum engineering. Amount is $300-$500. Two or three awards annually.

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

CIVIL ENGINEERING

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

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

North Star Concrete Company University of Minnesota Scholarship: See description under All Divisions.

ELECTRICAL ENGINEERING

Collins Radio Company Scholarship: For graduates or undergraduates in electrical engineering. Amount is tuition and incidental fee at resident rate.

Douglas Aircraft Scholarship: See description under Aerospace Engineering and Mechanics scholarships.

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

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

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

GEOLOGY and GEOPHYSICS

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

David K. Jensen Memorial Scholarship: To undergraduate students planning to continue with graduate work (or to graduate students) in geology or geophysics. $200-$400.

E. J. Longyear Memorial Scholarship: For undergraduate student in the fields of metallurgical engineering, mineral engineering, geology, and other earth sciences. Amount is $300-$400. Up to three awards annually.

MATHEMATICS

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

See scholarships under All Divisions.

MECHANICAL AND AEROSPACE ENGINEERING, SCHOOL OF

Rosemount Engineering Company Instrumentation Award: To the graduate or undergraduate student in the School of Mechanical and Aerospace Engineering judged by the school to have the greatest potential for the design and development of industrial aircraft and/or space instrumentation. Award is $400.

MECHANICAL ENGINEERING

American Institute of Industrial Engineers — Twin City Chapter: For qualified undergraduate in industrial engineering who is a member of A.I.I.E. Amount is $100.

American Institute of Plant Engineers Scholarships: Preference to a sophomore or junior who shows an interest in plant engineering and has taken courses in air conditioning, heat, and power.

American Society for Quality Control — Minnesota Section Scholarship: For undergraduate in industrial engineering. Amount is $200.

Central Warehouse Company Scholarship: To assist industrial engineering students whose training in engineering would qualify them as industrial management trainees.

Douglas Aircraft Scholarship: See description under Aerospace Engineering and Mechanics scholarships.

Ladish Company Scholarships in Mineral and Metallurgical Engineering and Mechanical Engineering: See description under Mineral and Metallurgical Engineering scholarships.

Maytag Scholarship in Engineering: For a male undergraduate in mechanical or industrial engineering, with administrative potential, who is willing to accept employment in private industry upon completion of his B.S. degree, the scholarship to be used during senior year. Amount is $500.

Mechanical Engineering Scholarship/Fellowship Fund: For undergraduate scholarship or graduate fellowship.

Pillsbury Company Scholarships: See description under Electrical Engineering scholarships.

Rosemount Engineering Company Instrumentation Award: See description under Mechanical and Aerospace Engineering, School of.

Schlumberger Foundation Scholarship: See description under Electrical Engineering scholarships.

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

Trane Scholarship: Student in mechanical engineering; excellent scholarship achievement, need; has given evidence of leadership among his peers. Three awards of $500.

Twin City Plant Engineers Society Scholarship: Preference shall be given to a student who will be either a junior or senior and who has indicated an interest in plant engineering or has taken courses in air conditioning or advanced heating and power.

MINERAL and METALLURGICAL ENGINEERING

American Institute of Mining, Metallurgical, and Petroleum Engineers, Minnesota Section, Scholarship: For undergraduate in the School of Mineral and Metallurgical Engineering. Amount is $500.

Cleveland-Cliffs Iron Company Scholarships: For entering freshmen in mineral engineering, metallurgical engineering, geological engineering, and geophysics; renewable for second year. Amount is $500. Two freshman awards annually; two sophomore awards annually. Transfer students entering third year are also eligible.

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

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

Ladish Company Scholarships in Metallurgical Engineering and Mechanical Engineering (Ladish Company, Cudahy, Wisconsin): For entering freshmen or advanced standing students in metallurgy or mechanical engineering who are willing to accept summer employment near Milwaukee; renewable annually. Amount is $300 for first 3 years, $350 for senior year. Two new awards annually.

E. J. Longyear Memorial Scholarships (E. J. Longyear Company, Minneapolis): For undergraduates and graduates in the fields of metallurgical engineering, mineral engineering, geology, and other earth sciences. Amount is $300-$500.

Mesabi Tire Scholarships: For students in mineral, metallurgical, or geological engineering who are from the Minnesota Iron Range, including Duluth. Amount is $250. Two or more awards annually.

School of Mineral and Metallurgical Engineering General Scholarship Fund: For students in the School of Mineral and Metallurgical Engineering.

PHYSICS

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

Schlumberger Foundation Scholarship: See description under Electrical Engineering scholarships.

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

II. GENERAL CURRICULAR REQUIREMENTS

In all units of the Institute of Technology, except the School of Architecture and Landscape Architecture, the undergraduate curricula are separated into a Lower Division and an Upper Division. The Lower Division consists of the first 2 years of work and the Upper Division consists of the remaining years of work required. In the School of Architecture and Landscape Architecture the 5-year curriculum in the Institute of Technology consists of 1 year of pre-architecture followed by 4 years in the School of Architecture and Landscape Architecture.

The basic curriculum of the first year in the Institute of Technology is the same for all divisions except that in the Departments of Chemistry and Chemical Engineering work in chemistry replaces the physics course. The requirements in engineering graphics also differ in the separate divisions. Students should check the curricula of the department in which they wish to major for the specific requirements in that department.

The curricula of the various departments differ further in the second year, and the student should again refer to the curriculum of the specific department in which he plans to major. A student in the College of Engineering may change departments within the college without loss of credit for any of the IT courses he has taken. He may, however, find that a change of departments will involve pursuing a somewhat irregular program before he can become completely regular in his new department. In order to change departments a student must file a petition and it must be approved by the department he seeks to enter before the change can be effective.

The emphasis in the Lower Division on the science and mathematics common to all the disciplines represented in IT thus offers the dual advantages of laying a solid foundation for the professional program of the Upper Division and of permitting ready transfer from one department to another within IT without loss of credits. Furthermore, the course work in the Liberal Education Requirements makes it possible for students who develop an interest in academic or professional programs other than those available in the Institute of Technology to transfer to another college with minimum loss of credit and time.

In the Upper Division, the student begins a specific course of study. He should at this time have more clearly defined professional aims because transfer of course credit from one department to another becomes progressively more difficult as the program becomes more specialized. Work in the liberal education area (nontechnical electives) is required throughout his program. It is important that the student be aware of the whole educational pattern of the Institute of Technology so that he may plan an overall program of required and elective courses that are consistent with his professional interests. The specific requirements for each degree are described in the curricula of the department or other unit offering that degree.

Liberal Education Requirement

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

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

Minimum Liberal Education Requirement

In addition to 9 credits of freshman English and otherwise required courses in mathematics and the physical sciences (which meet or exceed the All-University requirements for Categories 1 and 2), the Minimum Liberal Education Requirement consists of 6 credits from Category 3a, 6 credits from Category 3b, 9 credits from Category 4, and 9 additional credits from any of the categories except 1d and physics and chemistry courses. The work listed above is hereafter referred to as the "minimum distribution requirement."

LIBERAL EDUCATION CATEGORY REQUIREMENTS

1. Communication, Language, and Symbolic Systems
   a. English and foreign language communication skills
   b. Linguistics, rhetoric, logic
   c. Philosophical analysis
   d. Mathematics

2. Physical and Biological Sciences
   a. The physical universe
   b. The biological universe

3. Man and Society
   a. The analysis of human behavior and institutions (6 credits)
   b. The development of civilization: historical and philosophical studies (6 credits)

4. Artistic Expression (9 credits)
   a. Literature
   b. The arts

In curricula specifying liberal education courses in excess of the minimum distribution, the course catalog of the Council on Liberal Education is expanded to include offerings of the following departments or programs:

American Studies	Geography	Physical Education (see below)
Anthropology	History	Political Science
Art	Humanities	Psychology
Astronomy	Journalism	Social Science
Botany	Languages (Classical and Modern)	Sociology
Classics	Linguistics	Speech, Communication, and Theatre Arts
Earth Sciences	Music	Zoology
Economics	Philosophy	
English		

A maximum of 4½ transfer credits in religion will be accepted for graduation credit but may only be applied to any liberal education *elective* requirements in excess of the minimum distribution previously outlined.

A maximum of 3 credits in physical education will be allowed toward graduation with grade but may not be used to satisfy any part of the minimum liberal education requirement previously outlined.

Freshman English — Students must complete a minimum of 9 credits in English. Any students not required to take Comp X should take Engl 1-2-3. A student who is classified exempt from Freshman English by action of the Department of English may satisfy the 9-credit requirement by any combination of courses totaling 9 credits from the areas of language or literature including foreign language and foreign literature courses. He may also elect to satisfy the requirement with Engl 1-2-3. Entering freshmen who are approved for advanced standing by the Department of English will receive 6 credits toward the language-literature requirement. A student who elects more than 9 credits of English may use the additional credits toward the liberal education requirement specified for his degree program.

CATALOG OF SOME OF THE COURSES SUITABLE FOR FULFILLING THE LIBERAL EDUCATION REQUIREMENTS

(Students in the Upper Division are strongly urged to select courses numbered 50 and above — which may be taken on a P-N basis)

An additional list of suitable courses is available in 133 Main Engineering.

1. **Communication, Language, and Symbolic Systems**
   a. English and foreign language communication skills

Engl 1-2-3	Spch 5, 50, 51, 81, 106
Comm 1-2-3	Rhet 1-2-3-4, 22, 26, 47, 51
Comp 27-28	All beginning foreign language courses
Jour 106	

b. Linguistics, rhetoric, logic, philosophical studies

Anth 85, 180-181†
Clas 48, 68
Econ 40
Engl 165, 166
Ling 1-2-3
Spch 2, 51, 67, 106, 109
Soc 80-81
Stat 41

c. Philosophical analysis

Phil 1, 2, 70, 151, 154, 160, 162

2. **Physical and Biological Sciences**

a. The physical universe

Ast 11, 51
BioC 1
Geo 1, 2, 11, 22
NSci 6
Soil 19

b. The biological universe

Anth 170, 173, 175
Biol 1, 2
Bot 10, 12
Ecol 50, 51
Ent 1
GCB 51, 66, 68
MicB 53
Phsl 2, 51

3. **Man and Society**

a. Analysis of human behavior and institutions (minimum of 6 credits)

AgEc 1, 2, 3
Anth 1A, 2A, 80, 100, 150, 165
CPsy 80, 81
Econ B, C, 1T-2T†, 20, 50A-B
FamS 1, 1A, 25
Geog 1, 4, 41, 67, 78, 162
HEd 90, 101
Jour 3, 90, 109
Pol 1, 2, A, B, 25, 26, 30, 80, 81
Psy 1, 2, 4, 5, 6, 10, 55, 75
SSci 1, 2, 3, 51-52-53, 71-72-73
Soc 1, 1D, 2, 3, 14, 14A, 53
Spch 61

b. The development of civilization: historical and philosophical studies (minimum of 6 credits)

Anth 90
Clas 1, 2, 3, 4, 5, 6, 122, 123
Econ 80
Hist 1, 2, 3, 4, 5, 6, 11, 12, 13, 14, 15, 16, 17, 18, 23, 24, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63; 14A, 15A, 16A
Languages — Ger 68, 91, 92; Fren 60, 61, 62; Ital 60-61-62; Span 60, 61, 62; Heb 74, 75; Arab 161, 162; Russ 75-76-77; Ortl 76, 77
NSci 171, 172, 173
Pol 40, 60, 61
Phil 3, 50, 51, 52, 53, 105, 106, 107, 108, 109, 110, 150, 171, 182

4. **Artistic Expression** (minimum of 9 credits)

a. Literature

Clas 1, 2, 3, 4, 5, 6, 42, 80, 81, 82, 91, 92, 93
Engl 21, 22, 23, 37, 38, 39, 52, 53, 54, 55-56, 66-67, 72-73-74
Foreign language — literature courses, Jour 103
Hist 14A, 15A, 16A
Hum 1, 2, 3, 4, 1A-2A-3A, 11, 12, 13, 21, 22, 23, 51, 52, 53, 54, 61, 62, 63, 71, 72, 73
Rhet 31, 32, 33, 34, 41, 42, 43, 60
Spch 81

b. The arts

Anth 166
Arch 21, 51, 52, 53, 54, 55, 56
ArtS 10, 11, 20, 23, 24, 25, 32, 33, 40, 41, 45
ArtH 1, 2, 3, 4, 47, 50, 56, 57, 58
HEc 20, 21, 120
LA (Landscape Architecture) 21
Mus 1, 4, 31, 32, 33, 34, 35, 36, 39, 40, 41, 42, 43, 43S, 44S, 45S, 46, 47, 48, 49 (see also 11-30 for individual instruments)
Spch 3
Th 11, 12, 21, 22, 23

Technical Electives

Most curricula include elective courses in mathematics, in the physical sciences, and in engineering. In individual departments, they may also include biological sciences, other than those listed in Category 2b. Students should consult the departmental curricula for details.

Optional or "Free" Electives

Most departmental curricula provide a minimum of 9 free elective credits, for which the student has the option of selecting either technical or nontechnical courses. If the student selects nontechnical courses, these credits are over and above the minimum liberal education requirements of 39 credits.

General College Transfer Students

Transfer of credits from General College for students admitted into the Institute of Technology is subject to the following conditions:

1. Only General College courses in which a student makes a grade of C or better will be approved for credit. However, see condition 3 below.
2. Credits in courses offered by the General College will be approved by petition only. They will not be included in the computation of the grade point average.
3. The requirement of 9 credits of the GC 31 sequence (except 31D) may be used to meet the 9-credit language-literature requirement. However to receive such credit the student must earn a grade of "top C" (grade C7) each quarter.
4. The Liberal Education Category Requirements can be satisfied only with courses specified in the catalog. If, however, a student has completed courses which are included both in the Arts College "overlap list" available in 133 Main Engineering (courses for which credit may not be received if equivalent courses have been taken) and in the Liberal Education Catalog, one category requirement may, by petition, be satisfied by such courses. The remaining two category requirements must be met by courses specified in the catalog.

5. Additional General College courses may, by petition, be used to satisfy the elective requirements; however, the total credits approved shall not exceed 20 credits in addition to credits toward the language-literature requirement.

Requirements for IT Students Enrolled in ROTC

1. No proportionate credit will be allowed for partial completion of any ROTC program.
2. Academic courses which are allowed in the ROTC program as substitute courses and which satisfy requirements for graduation from IT will receive full credit.
3. All ROTC courses which have been accepted for credit by the related academic departments will be approved for credit toward graduation in IT as if the course had originated in that academic department. Current lists of such courses may be obtained in 133E. Such courses may be applied toward degree requirements even though the student does not complete the ROTC program.
4. Any student who completes an ROTC program will be allowed up to 9 credits toward graduation, either as electives or as technical electives, in addition to those allowed in requirement 3 above. These additional credits may not be used toward meeting the minimum liberal education requirement of 39 credits.
5. Credits for ROTC courses based on a comprehensive examination for military service are not accepted in IT.
6. Transfer credit for ROTC courses needed to complete an ROTC program at the time of graduation may be petitioned.

Additional Course Information

Credit for Summer Employment — Consult your department or college office regarding credit for summer employment. Approval by the department must be obtained before employment if credit is desired.

Extension Courses — Credits will be accepted from the General Extension Division toward a degree in the Institute of Technology provided the student receives advance approval from his department by petition.

III. CURRICULA

The objectives, program description, and detailed requirements for each of the degrees are given in the following order:

A. College of Engineering

B. School of Architecture and Landscape Architecture

C. School of Chemistry

D. School of Earth Sciences (Department of Geology and Geophysics)

E. School of Mathematics

F. School of Physics and Astronomy

G. Department of Computer, Information, and Control Sciences

COLLEGE OF ENGINEERING

General Description of Engineering Curricula — It is desirable to clarify the general approach used in the various engineering curricula before discussing specific course requirements. This approach involves the interweaving of the elements of basic science, engineering science, professional engineering work, and design into one expanding pattern.

To build the sound foundation required in all engineering work, the first 2 years of all engineering curricula emphasize the basic sciences of mathematics, physics, and chemistry. Freshmen take work also in English and graphics.

A primary objective during the second and third years is continued training in science, but at this level the term engineering science becomes more appropriate. In such courses as solid and fluid mechanics, thermodynamics, heat transfer, electrical circuits and fields, and materials, efforts are made to coordinate and extend the basic sciences to simplified and idealized engineering situations. In these courses the primary concern is still analysis.

Starting in the third and fourth years, the professional engineering viewpoints begin to appear in some of the courses. This work not only extends further the engineering science coverage, again with emphasis on analysis, but also treats the difference between the simplified-idealized conditions assumed in earlier work and the real engineering situations. Recognition of this important difference and its significance is a vital part of the engineer's development.

During his fourth year, some of the courses begin to involve design concepts. Thus, not only is the analysis of engineering situations continued but also the ideal of synthesis, the putting together of combinations of ideas and components, is introduced. Creativity in this sense is another important aspect of the engineer's development. Design work is intended also to develop engineering maturity through a case approach so that such important concepts as the "engineering compromise" and "increment-of-return" begin to assume meaning.

LOWER DIVISION

Basic Curriculum for First 2 Years — The curriculum for the first 2 years is, with certain exceptions, the same for all students in the College of Engineering. The courses included in the first 2 years are listed as follows:

First Year

	Credits — f	w	s
Engl 1-2-3 — Freshman English	3	3	3
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Phys 21, 22T — General Physics	..	4	4
Phys 21A, 22A — Physics Laboratory	..	1	1
EG 25 — Engineering Graphics	4	..	..
Liberal education electives (see Index for Category Requirements)	3-5	3-5	3-5
Total credits	15-17	16-18	16-18

Students will be advised individually regarding carrying the maximum credit loads indicated. Electives are to be chosen from Categories 3a, 3b, or 4, or other approved electives from the Catalog of Courses suitable for fulfilling the Liberal Education Requirements (see page 36).

Second Year

(See individual department recommendations)

	Credits
Math 31-32 — Calculus IV-V	10
GeCh 14-15 — General Principles of Chemistry	8
Phys 23T, 23A, 50T, 50A — General Physics; Modern Physics; Physics Laboratory	8-10
Liberal education electives and additional technical courses (specified by department)	22-25
Total credits	48-53

General Suggestions for Selecting Electives — A review of the various third-year and fourth-year curricula shows that the student is offered a significant number of electives, both technical and nontechnical. He may thus tailor a program to suit his individual objectives. This opportunity, however, places on him increased responsibility to be well informed on the possible variations in engineering education. The student is therefore strongly urged to discuss the selection of electives with his adviser. (See section on Student Personnel Services.) However, to provide some preliminary background for deciding among the various electives offered, the nature of the engineer's job and its general relationship to the engineering curriculum is discussed on succeeding pages.

It is important in choosing electives to distinguish between the classification of engineering by professional fields and by engineering function. Since students must select a professional field for concentration, they are familiar with such fields of engineering as aeronautical, civil, electrical, mechanical, etc. The concept of engineering function, however, although of great value in career guidance, is frequently overlooked.

From a functional point of view, engineering jobs may be classified as: research, development, design, planning, construction and production, sales, and service engineering. In recent years scientific management has also become of great interest to engineers. The order of listing is roughly from the most technical and analytical functions to those involving the greatest association with people and the business world. Jobs in all professional fields of engineering involve these and other functions. Each student should appraise his aptitudes and past performances critically in order to determine which engineering function best matches his talents and personality. He will then be in a position to choose his electives and guide his career development more intelligently.

In general, students with excellent grades in mathematics, physics, and other analytical courses who lean toward basic scientific engineering are encouraged to direct their efforts toward the research, development, and design functions. These require a strong background in mathematics and in the basic physical sciences, and this should be reflected in the student's choice of electives. Such students should also seriously consider graduate work; in fact, work beyond the Bachelor's degree is almost essential for high-level attainment in research and development.

On the other hand, students with a leaning toward professional engineering practice and business will probably find that the engineering functions which interest them most are planning, construction and production, operation, sales, and service. Students interested in these functions should consider the various departmental options. Furthermore, since the functions require competence in engineering practices, economics, and psychology, students may well take electives in these areas.

The above generalizations are oversimplified and intended as a preliminary guide only. Students are strongly urged to consult with their advisers so that the numerous individual factors of importance in deciding a program of electives may receive thorough consideration.

UPPER DIVISION

Degree Programs — Detailed Upper Division curricula for each degree program in the College of Engineering are presented in the following sections.

- Aerospace Engineering and Mechanics
- Agricultural Engineering
- Civil Engineering
- Electrical Engineering
- Geo-Engineering
- Mechanical Engineering (and Industrial Engineering Option)
- Metallurgy-Materials Science
- Mineral Resources Engineering (Mining and Petroleum Engineering Production Processes; Mineral and Metal Extractive Processes)

Aerospace Engineering and Mechanics

(School of Mechanical and Aerospace Engineering)

The objective of this program is to prepare students for the broad range of problems encountered in aerospace systems. In order to cope with the rapidly changing objectives which characterize an engineering field so close to the frontiers of science, the curriculum emphasizes a broad engineering science base rather than selected specialties. Specific knowledge on specialized devices is likely to become obsolete during the student's professional life, but a broad engineering science background will generally remain applicable to the solution of the changing problems and new situations characteristic of modern technology. Furthermore, with a sound engineering science background students are not bound to any specialized area but have the flexibility to cross over into other fields of technology and even multidisciplinary fields.

A major part of the course work offered by the department lies in the area of fluid mechanics and solid mechanics pertinent to *aerospace engineering.*

In addition to the required courses, sufficient electives are offered to permit students to develop such functional interests as research, development, design, production, operation, application, or management.

The 4-year curriculum leads to the degree of bachelor of aeronautical engineering, B.Aero.E. in which a broad "aerospace" viewpoint is emphasized. In addition to the prescribed courses, sufficient approved electives must be taken to complete a minimum of 200 credits for graduation.

There are many job opportunities within the department for outstanding undergraduate and graduate students. The research program within the department is extensive and vigorous, and this provides not only good job opportunities but also excellent engineering work experience. In addition, many undergraduate and graduate students are employed as laboratory assistants, homework correctors, and as general assistants for the professorial staff.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering. For nontechnical requirements see note on electives following fourth-year program.

Second Year

	Credits — f	w	s
Math 31-32, 33 — Calculus IV, V, VI	5	5	5
Phys 23T, 50T, 51T — General Physics; Modern Physics; Statistical Physics	4	4	4
Phys 23A — Physics Laboratory	1	..	..
GeCh 14-15 — General Principles of Chemistry	4	4	..
MM 35, 37, 36 — Statics; Deformable Body Mechanics; Dynamics	4	4	4
Aero 5 — Aerospace Survey and Laboratory	..	1	..
Nontechnical Electives	..	..	3-5
Total credits	18	18	16-18

UPPER DIVISION

Third Year

	Credits — f	w	s
Aero 100A — Kinematics and Dynamics of Fluid Flow	4	..	..
Aero 101A — Incompressible Boundary Layer Theory	..	4	..
Aero 102A — Shock Waves and Compressible Fluid Flow	..	..	4
Math 65 — Introduction to Computer Programming	4	..	..
MM 193 — Introduction to the Theory of Mechanical Vibrations	3	..	..
MM 150 — Rheology and Strength of Solids	..	3	..
ME 30A — Thermodynamics	..	4	..
ME 133 — Heat Transmission	..	..	3
EE 46, 47 — Circuits; Electronics (see note below)	4	4	..
Stat 90E — Introduction to Probability and Statistics	..	..	3
Electives (see statement below)	0-3	0-3	6-8
Total credits	15-18	15-18	16-18

Fourth Year

	Credits — f	w	s
Aero 145-146 — Aeromechanics Laboratory I, II	3	3	..
Aero 106 — Aerodynamics of Lifting Surfaces	3	..	..
Aero 115 — Aerospace Structures I	..	3	..
Electives (*see statement below*)	9-12	9-12	15-18
Total credits	15-18	15-18	15-18

Note — With approval of adviser EE 30-31 may be substituted for 46, 47.

ELECTIVES

The total credit requirement in the elective category for graduation is 61 (22 technical, 30 nontechnical and 9 free). The range of elective credits shown in the program above is intended to enable the student to pace himself (the total of the minimum elective credits shown is 48 and the total of the maximum is 76).

For liberal education elective requirements, see Section II. Spch 50 (Public Speaking) is strongly recommended as a liberal education elective.

In the technical elective area, at least 12 credits must be obtained in 100-series aeronautics or mechanics and materials courses. Other suitable technical courses may be substituted by petition. Aero 9, Basic Ground School (3 cr), offered in the Extension Division, will be accepted by petition as a technical elective if the student has completed at least 3 hours of certified dual flight instruction.

Agricultural Engineering

Agricultural engineers are concerned with the development and application of new or improved processes, machines, facilities and systems for food production, fiber production, and natural resources management. The agricultural engineering curriculum is planned to develop a basic knowledge of the physical sciences and engineering and their application to these problems. The curriculum provides for developing a general understanding of biological science, since agricultural engineers often deal with plants, animals, and biological materials. Economics, other social sciences, humanities, and communications are included so that agricultural engineering graduates can evaluate proposed solutions to engineering problems, including their effects on man and his environment.

A 4-year curriculum leading to the bachelor of agricultural engineering, B.Ag.E., is offered in the Institute of Technology in cooperation with the College of Agriculture, Forestry, and Home Economics. A total of 200 credits is required for graduation.

Each student with the assistance of a faculty adviser plans a program to suit his individual interests and needs. Students may specialize in one of the following option areas during the last 2 years: power and machinery engineering; soil and water engineering; or structures, environment, and processing. These options are developed with both agricultural engineering electives and those from other fields. By choice of electives, a student may prepare himself specifically for a career in design, development, sales or management with a wide variety of industries, business firms, and public service agencies for expanding food production in developing countries, or for graduate study leading to a career in research and/or education.

An engineering intern (cooperative education) program providing practical training in industry in addition to the formalized training is available to qualified students. This program requires 5 years for graduation. Students may begin their work assignments in industry in the summer following either the first or the second year. Additional work periods are as follows: the spring and summer of the third year; the winter of the fourth year; the summer of the fourth year; and the fall of the fifth year. These work assignments are supervised both by the employing industry and the department.

Transfer students can be accommodated easily in either the regular program or the engineering intern program. Students planning to transfer should consult with the department as early as possible, preferably before beginning their second year of study.

For financial assistance, students should contact the department for detailed information about scholarships, part-time employment, and the engineering intern program.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering. Rhet 1, 2, and 3 may be substituted for Engl 1, 2, and 3. AgEc 1 and 2 are suggested in the first year to satisfy the liberal education requirement for Group 3a, with any additional electives from Group 2 (see statement under second year).

Second Year

	Credits — f	w	s
AgEn 20 — Introductory Agricultural Engineering	..	..	3
Math 31-32 — Calculus IV, V	5	5	..
Phys 23T, 23A — General Physics; Physics Laboratory	5	..	..
Phys 50T — Modern Physics	..	..	4
GeCh 14-15 — General Principles of Chemistry	4	4	..
MM 35, 37, 36 — Statics; Deformable Body Mechanics; Dynamics	4	4	4
EE 46 — Circuits	..	4	..
Electives (see statement below)	..	..	6
Total credits	18	17	17

Second year electives should be chosen from Group 2 of the liberal education requirement. Biol 1, 2, BioC 1, Geo 1 and/or Soil 19 are suggested.

UPPER DIVISION

Third Year

	Credits — f	w	s
AgEn 90, 94 — Soils Engineering; Erosion Control Engineering	3	3	..
AgEn 91 — Design and Management of Agricultural Machinery	..	3	..
AgEn 97 — Agricultural Structures Design	..	..	3
CE 101A — Fluid Mechanics	4	..	..

ME 30A, 31A, 133 — Thermodynamics; Heat Transmission (see statement below)	4	4	3
ME 22 — Analysis of Mechanism Systems	4	..	..
Electives (see statement below)	3	7	11
Total credits	18	17	17

Students in the engineering intern program should schedule ME 133 in the winter quarter.

Fourth Year

	Credits — f, w, s		
AgEn 121 — Agricultural Tractors	3	..	..
AgEn 124 — Drainage and Irrigation Engineering	3	..	..
AgEn 127 — Agricultural Process Engineering	3	..	..
AgEn 160 — Agricultural Engineering Instrumentation	..	..	3
Agricultural engineering electives — 141, 161 or 144, 164 or 147, 167	..	3	3-4
Engl 85 — Technical Writing	..	3	..
Electives (see statement below)	7	10	9-10
Total credits	16	16	16

ELECTIVES

The electives should be chosen to fulfill the liberal education requirements and to develop the selected option and interest discussed previously. Spch 50 (Public Speaking) or Rhet 22 (Public Speaking) is strongly recommended as one of the electives to fulfill the liberal education requirements.

Civil Engineering

General — Civil engineers serve the public as planners, designers, and supervisors of transportation systems, structures, pollution control facilities, water resource projects, and other essential creations of our civilization. Although civil engineers are needed in developing areas where power, building, and transportation complexes are essential for growth, they are needed even more in an urban society. Population concentrations create new problems in all areas of civil engineering. The civil engineer, in the future as in the past, will therefore play an important role in adapting the environment for the health and general benefit of man. He requires the highest technological competence. He also needs to understand government structure and social goals so that he can work effectively with men of nontechnical background. The need for well-educated civil engineers is great and there are ample opportunities in both private practice and public service. Graduates may enter careers in design, construction, maintenance, management, research and development, or teaching.

The curriculum leading to the bachelor of civil engineering degree (B.C.E.) prepares men and women to enter this profession. This 4-year program is continually studied and revised by the faculty with a view to providing the best in fundamental scientific knowledge and engineering understanding. It stresses a command of basic science and mathematics. It fosters the development of a broad humanistic background through a generous allowance of "free" elective courses, in addition to those associated with the liberal education requirements of the Institute of Technology. These fundamental studies are supplemented by applied courses in five major areas of civil engineering: structural design, sanitary engineering, surveying and land development, transportation engineering, hydraulics and water resources engineering.

With the rapid development of technology in mind, many students prepare themselves for advanced professional work by a year of study beyond the B.C.E. degree. Those with superior academic records may be admitted to graduate study as soon as they are within 9 credits of the B.C.E. degree. Nine credits toward the Master's degree may be earned during the last term of undergraduate study. The prospective student should apply for admission to the graduate degree program of his choice; either the design-oriented professional Master's degree program (apply to chairman, Department of Civil Engineering) or the research-oriented master of science degree program (apply directly to the Graduate School). For details of the graduate program reference should be made to the *Graduate School Bulletin.*

Transfer Students — The Department of Civil Engineering and Hydraulics welcomes transfer students from junior colleges, state colleges, liberal arts colleges, and branches of the University of Minnesota. Students who enter by transfer receive credit for suitable course work taken before entering the Institute of Technology. Transfer students often have a slight excess of nontechnical credits on admission to the Institute of Technology and a corresponding slight deficiency of technical courses. Those who enter at the beginning of the third year, or earlier, may expect to complete the requirements of the B.C.E. degree in a total of 4 years, i.e., at the same time as if they had entered the Institute of Technology directly from high school. Students who transfer after more than 2 years at another college or who are candidates for both liberal arts and engineering degrees usually need a total of more than 4 years to complete the requirements of the B.C.E. degree. Inquiries in individual cases should be directed to the attention of the "Adviser for Transfer Students" in the Department of Civil Engineering and Hydraulics.

Honors Program — A civil engineering honors program, open to Upper Division students with GPA of 3.00 or better, provides opportunity for increased flexibility in program arrangements. Participants in the honors program complete the same total number of credits as those who are not, but they are exempted from certain civil engineering required courses. Their programs are arranged in consultation with their adviser and the departmental honors program committee. The object of this flexibility is to permit greater depth of training in specific areas and to encourage superior preparation for graduate study. Greatest benefit will be obtained by entry to the program at the start of Upper Division work. For further details application should be made to the department office.

Financial Aid — Many civil engineering students support themselves during the academic terms by savings from subprofessional summer work on civil engineering projects. The department approves of this and assists in arrangements for summer employment. Apart from financial advantages, the work experience, properly supervised, supplements academic training. A scholarship program is also maintained through the cooperation of the civil engineering and surveying professions in Minnesota. Further assistance is available through employment on departmental research programs. These provide a valuable introduction to engineering investigation as well as a means of financial support. Inquiries about financial aid or employment should be directed to the chairman of the department Student Welfare Committee. The initial inquiry should be made as early in the academic year as possible.

Elective Courses — In addition to the required course work listed below, the 4-year program leading to the degree of bachelor of civil engineering includes 54 credits of elective courses. Thirty of these credits, together with 9 credits of the first-year required course sequence in English, will be needed to complete the liberal education requirements of the Institute of Technology. Twelve of the remaining 24 elective credits must represent Upper Division course work in the Department of Civil Engineering and Hydraulics. The other 12 elective credits are "free" elective courses. They may be either technical or nontechnical in character. Course work taken as part of a completed ROTC program will be accepted for 9 of these free elective credits.

Each student is assigned a department adviser. Close consultation between student and adviser is needed to obtain maximum benefit from the University course of study. In particular it is recommended that students with special career objectives see their adviser or the department head. By appropriate selection of elective courses a student may prepare himself for specialization in urban planning, construction, water resources or sanitary engineering as well as the other main subdivisions of civil engineering. Combined curricula in civil engineering and other colleges are open to qualified students. Details may be secured by applying to the department office.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering, page 41.

Take CE 1, Civil Engineering Orientation (1 cr) in fall quarter.

Nine elective credits should be completed during the first year.

A student should elect courses which will aid in satisfying the liberal education requirements as given on page 35. It is suggested that the electives be chosen from the following sequences:

Econ 1T and 2T — Principles of Economics (3 cr each)
Pol 1 and 2 — American Government and Politics (3 cr each)
Soc 1 and 3 — Man in Modern Society (3 cr); Social Problems (3 cr)
6 cr of history or humanities

Second Year

It is recommended that the following curriculum be completed during the second year.

	Credits — f	w	s
Math 31-32 — Calculus IV, V	5	5	..
MM 35, 37 — Statics; Deformable Body Mechanics	4	4	..
Phys 23T, 23A, 50T — General Physics; Physics Laboratory; Modern Physics	see Note below		
GeCh 14-15 — General Principles of Chemistry	see Note below		

CE 101A — Fluid Mechanics	..	..	4
Introductory course in computer programming	..	1-4	..
Electives to be arranged	3	3-0	3-6
Total credits	17	17	15-18

Note — GeCh 14, 15 and Phys 23T, 23A, 50T should be scheduled with respect to *Class Schedule* to permit more flexibility in elective choice throughout the year.

The department recommends that the electives (9-12 cr) be arranged with one of the following objectives in mind:

1. Completion of specified liberal education group requirements.
2. Complete basic courses in a given area outside of civil engineering in preparation for further study in the chosen field (biology, geology, economics, geography, political science, business administration, etc.).
3. Complete introductory course sequences within civil engineering (i.e., CE 61A, 63A, 64A) or individual courses (i.e., CE 53, CE 100).

The exact details of the student's program should be carefully developed through consultation with his adviser.

UPPER DIVISION

Third Year

	Credits — f	w	s
Structural engineering sequence (either 81, 82, 83 or 81, 136, 141)	4	4	4
Water resources sequence (160, 161)	4	3	..
Sanitary engineering sequence (170, 171)	..	3	3
Additional credits to be arranged	9	7	10
Total credits	17	17	17

In addition to the courses listed above, the following required courses, if not taken during the second year, are usually completed by the end of the third year: 61A, 63A, 64A, 51, 52 and 53.

Students who wish to emphasize structural engineering and those who are uncertain of their field of specialization should complete the analysis sequence 81, 82, 83 in the third year and the design sequence 141, 136 in the fourth year.

Students who know that they wish to emphasize another area than structures should register for the design sequence 81, 141, 136.

Fourth Year

In addition to completing the required courses, CE 100, 121, 146, 147 and MM 36, ME 30A and EE 46, sufficient electives (nontechnical, technical, or free as required) must be completed so that a total of 200 credits are presented to satisfy the requirements for the B.C.E. degree. It should be noted that MM 36, ME 30A, and EE 46 may be taken during the second, third, or fourth year depending on the best arrangement of the student's individual program.

Summary

The following is a summary of the course requirements for the B.C.E. degree.

1. Required courses: (146 cr)

   Math 21A, 22A, 23A, 31, 32; Phys 21, 21A, 22T, 22A, 23T, 23A, 50T; GeCh 14-15; EG 25; MM 35, 36, 37; ME 30A; EE 46; CE 1, 51, 52, 53, 61A, 63A, 64A, 101A, 160, 161, 170, 171, 100, 121, 146, 147; either 81, 82, 83 or 81, 141, 136; 9 credits of Freshman English; course in computer programming.

2. Elective Courses: (54 cr)

   See page 48.

Electrical Engineering

Many of today's electrical engineers encounter assignments in fields that developed after their formal education was completed, e.g., integrated circuits, computer technology, solid state electron devices, and the simulation and design of large-scale engineering systems. It can be expected that results from basic scientific research will continue to produce new technologies in the decades ahead. The electrical engineering curriculum is designed to prepare its graduates not only to cope with their first assignment but to provide the necessary fundamental background for continued professional development. The education to meet this objective is based on the parallel development of two major themes. The first theme concerns electromagnetic phenomena and the electronic properties of materials essential to the understanding of physical devices. The other theme develops the techniques for analysis and synthesis of engineering systems. The required curriculum provides essential scientific and engineering background; elective freedom in the senior year allows for concentration in specialized areas of current interest. To provide for the latter, each student elects one of four options:

1. Circuits and Electronics
2. Computer Science
3. Materials and Devices
4. Systems

These represent a division of the field of electrical engineering (with overlapping boundaries) and serve as a useful guide to the student in his selection of electives. The option is identified on the student's transcript.

The nontechnical content of the curriculum represented by the liberal education requirement contributes to the student's professional preparation by enhancing his appreciation of the social, economic, and political forces surrounding engineering decisions.

The curriculum leads to the degree of bachelor of electrical engineering, B.E.E. A total of 200 credits is required for graduation.

Students interested in graduate study should inform their adviser preferably during the third year. Early notification provides time to select the most appropriate technical electives as preparation for graduate education.

The Honors Program within the Electrical Engineering Department is offered to superior and highly motivated students who are capable of and interested in a deeper and broader view of science and engineering. Qualified students may enter the program with the concurrence of the faculty any time up to the beginning of the senior year. The program features a close interaction with senior faculty members in seminars and in special projects. For those students in the Honors Program a considerable portion of the senior year is made freely elective to accommodate individual interests. The department encourages students to discuss the Honors Program with their faculty adviser or the chairman of the Honors Program Committee.

Electrical engineering students who complete one of the ROTC programs may apply the associated 9 credits to the requirements for free and/or technical electives within the electrical engineering curriculum.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering.

Second Year

	Credits — f	w	s
GeCh 14-15 — General Chemistry	4	4	..
Math 31-32, 33 — Calculus IV, V, VI	5	5	5
Phys 23T, 50T — General Physics; Modern Physics	4	4	..
Phys 23A — Physics Laboratory	1	..	..
EE 30-31 — Circuit Analysis	..	3	3
EE 30A-31A — Electrical Engineering Laboratory	..	1	1
Stat 90E — Introduction to Probability and Statistics	..	..	3
Liberal education electives (see Index)	3	..	3-5
Total credits	17	17	15-17

UPPER DIVISION

Third Year

	Credits — f	w	s
EE 64-65 — Electronics I-II	4	4	..
EE 66 — Nonlinear Electronic Circuits	..	..	4
EE 74-75 — Electromagnetic Fields I-II	4	4	..
EE 107-108 — Linear System Analysis	..	3	3
EE 84-85-86 — Junior Electrical Engineering Laboratory	2	2	2
Engl 85A-B-C — Technical Writing for Engineers	1	1	1
Math 60A — Operational Methods for Linear Systems	3	..	..
MM 36 — Dynamics	..	..	4
Liberal education electives (see Index)	3	3	3
Total credits	17	17	17

Fourth Year

	Credits
EE 76 — Electromagnetic Fields III	3
2 credits in the following: EE 76A — Electromagnetic Fields Laboratory; EE 110A — Electromechanics Laboratory; EE 117A — Electronic Circuits Laboratory	2
Option program (see details below)	34
Free electives	8
Liberal education electives	4-6
Total credits	51-53

Option 1 — Circuits and Electronics

a. EE 117 — Linear Electronic Circuits
EE 110 — Electromechanics
(or) EE 119 — Electrical Engineering Materials

b. Two EE elective sequences, at least one selected from those listed below:
EE 127A-B — Network Synthesis
EE 129A-B — Control Systems
EE 131A, B — Applied Electronics I-II
EE 141A-B — Physical Electronics

c. Additional Upper Division technical electives (EE or non-EE) to complete the required total of 34 credits.

Option 2 — Computer Science

a. EE 110 — Electromechanics
(or) EE 117 — Linear Electronic Circuits
EE 119 — Electrical Engineering Materials
EE 135A-B — Principles of Computer Engineering
(or) EE 187A, 190B-C — Information Theory and Coding; Digital Computer Systems
Math 100A — Mathematics of Symbol Manipulation Systems
Math 164, 165, 166 — Theory of Programming Modern Digital Computers**

b. Additional Upper Division technical electives (EE or non-EE) to complete the required total of 34 credits. The courses listed below are recommended:
EE 129A-B — Control Systems
EE 130A-B — Applications of Electromagnetic Theory
EE 131A, B — Applied Electronics I-II
EE 138A-B — Electric Power Systems
Math 100B-C — Mathematics of Symbol Manipulation Systems
Math 101A-B-C — Non-Numeric and Systems Programming**
Math 184, 185-186 — Elementary Numerical Analysis in Engineering; Numerical Analysis in Engineering

Option 3 — Materials and Devices

a. EE 110 — Electromechanics
(or) EE 117 — Linear Electronic Circuits
EE 119 — Electrical Engineering Materials

b. At least 12 cr selected from the courses listed below:
EE 130A-B — Applications of Electromagnetic Theory
EE 131A-B — Applied Electronics I-II
EE 134A-B — Direct Energy Conversion

** Capable students may, with their adviser's approval, interchange Math 164, 165, 166 with the 3rd-year liberal education electives in order to satisfy the prerequisite for Math 101A-B-C by the 4th year.

EE 141A-B — Physical Electronics
EE 150, 151, 152 — Dynamical, Thermodynamic, Statistical-Mechanical Methods in Electrical Engineering
(or) Phys 123, 124, 125 — Thermodynamics; Statistical Mechanics; Introduction to Solid State Physics
EE 153 — Introductory Quantum Mechanics for Engineers
EE 173A-B-C — Semiconductor Properties and Devices
Phys 134, 135 — Experimental Optics Laboratory; Contemporary Optics

c. Additional Upper Division technical electives (EE or non-EE) to complete the required total of 34 credits.

Option 4 — Systems

a. EE 110 — Electromechanics
(or) EE 117 — Linear Electronic Circuits

b. Two EE elective sequences, at least one selected from those listed below:
EE 127A-B — Network Synthesis
EE 128A-B — Communications
EE 129A-B — Control Systems
EE 138A-B — Electric Power Systems
EE 147A-B — Applied Electromechanics

c. 9 credits in courses in statistics or mathematical analysis numbered 130 or above.

d. Additional Upper Division technical electives (EE or non-EE) to complete the required total of 34 credits.

ELECTRICAL ENGINEERING ELECTIVES

Able students may, with the concurrence of their adviser and the course instructor, replace an EE elective sequence with the advanced course listed at the right.

	Advanced Course
EE 127A-B — Network Synthesis	EE 170, 171-172
EE 128A-B — Communications	EE 187A, 186B, C
EE 129A-B — Control Systems	EE 194A-B, 195A or 196
EE 130A-B — Applications of Electromagnetic Theory	EE 167-168-169
EE 131A, B — Applied Electronics I-II	
EE 134A-B — Direct Energy Conversion	
EE 135A-B — Principles of Computer Engineering	EE 187A, 190B-C
EE 138A-B — Electric Power Systems	
EE 141A-B — Physical Electronics	
EE 147A-B — Applied Electromechanics	
EE 150, 151, 152 — Dynamical, Thermodynamic, and Statistical-Mechanical Methods in Electrical Engineering	

Geo-Engineering

(School of Mineral and Metallurgical Engineering)

A 4-year program is offered that leads to the degree of bachelor of geo-engineering, B.GeoE. A minimum of 203 credits, including field trips, is required for graduation.

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

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

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

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

The mineral industries, including metal mining, petroleum and industrial raw materials, where his major concerns are analysis and design in the exploration and development of mineral resources. This will include problems in mineral economics, mineral valuations, application of geochemical, geophysical, and geologic principles and techniques. He may also advise and assist mining engineers on problems of ore reserves, quality control, the effects of geologic factors on rock behavior and many others.

City and regional planning, involving problems in water supply, land evaluation, waste disposal, reservoir usage and zoning, legal aspects of geologic conditions and others.

Government bureaus and other agencies involved in such tasks as the application of nuclear explosives for peaceful uses.

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

The geological engineering program is recommended as a good foundation for graduate study in rock mechanics, the new and rapidly developing field devoted to the study of the mechanisms of deformation of rock and rock masses and the technological implications of such deformations.

Transfer Students — Students from junior colleges, state colleges, liberal arts colleges, and branches of the University of Minnesota may transfer to the School of Mineral and Metallurgical Engineering and continue academic work toward the degree of B.GeoE. Students will receive transfer credit for suitable course work taken prior to entering the Institute of Technology, and study programs to suit individual curriculum requirements will be arranged with a departmental adviser.

Faculty Adviser — The undergraduate student is assigned a member of the faculty as his adviser who will assist the student in selecting courses for his curriculum. The adviser will serve as a consultant during the student's scholastic career.

Electives — A student should consider the areas of his principal interests and discuss with his adviser a selection of technical electives best suited to serve his needs and promote his interests. A student who intends to take graduate work should consult with the adviser so as to elect courses that prepare him for his graduate specialty.

Undergraduate Job Opportunities — The research programs in the department provide job opportunities for stimulating engineering and research experience, and for developing scientific interest and motivation. The student is encouraged to obtain summer job experience in the field of his interest.

Master of Engineering Program — Graduate study is offered leading to the M.S., Ph.D., and M.GeoE. The latter program is designed for students particularly interested in planning, design, operation, or management. The candidate should have a 2.50 GPA to enter the master of engineering program.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering.

Second Year

	Credits — f	w	s
Math 31-32 — Calculus IV, V	5	5	..
Introductory course in computer programming	..	..	1-4
Phys 23T, 23A; 50T — General Physics; Physics Laboratory; Modern Physics	..	5	4
GeCh 14-15 — General Principles of Chemistry	4	4	..
GeCh 6 — Principles of Solution Chemistry	..	..	4
MM 35, 37 — Statics; Deformable Body Mechanics	4	4	..
ME 99 — Introduction to Engineering Analysis	..	..	3
MinE 1 — Mineral Engineering Laboratory	..	..	1
Liberal education electives (see Index for Category Requirements)	3	..	3-0
Total credits	16	18	16

UPPER DIVISION

Third Year

	Credits — f	w	s
GeoE 13 — Geo-Engineering Surveying	..	..	3
GeoE 15 — Survey Field Work	..	..	2
GeoE 111 — Mineral Exploration	3	..	..
GeoE 131, 132 — Rock Mechanics I, II	..	3	3
MinE 137, 113 — Computer Application in Mineral Engineering; Principles of Mineral Engineering III — Earth Fluids and Flow	3	..	3
CE 61A, 101A, 53 — Survey Engineering; Fluid Mechanics; Elements of Soil Mechanics	3	4	3
Geo 11, 62 — Introductory Physical Geology; Introductory Mineralogy	5	5	..
Electives	3	6	3-6
Total credits	17	18	17

Fourth Year

	Credits — f	w	s
GeoE 133, 161-162 — Rock Mechanics III; Geo-Engineering Analysis	3	2	3
Geo 63, 65 — Introductory Structural Geology; Introductory Field Geology	3	..	2

Geo 131 — Ground Water Geology	..	..	3
Geo 155 — Mineral Deposits	..	3-0	..
(or) CE 157 — Slope Stability	..	..	0-3
Geo 175, 176A, 177 — Gravity and Magnetic Exploration; Principles of Refraction Seismic Exploration; Electrical Exploration	2	2	3
Electives	9	7-10	3-0
Total credits	17	17	17

A Geological Field Course of not less than 4 weeks (6 credits) is required for graduation.

Not less than 203 credits, including field trip, are required for graduation.

ELECTIVES

All elective courses must be chosen in consultation with the student's adviser. Technical elective courses are to be selected from the following two groups. Adviser's consent necessary for exceptions.

A. For students with a principal interest in site investigation, rock mechanics, etc.

GeoE 116 — Geo-Engineering I
GeoE 117 — Tunnel Technology
GeoE 134 — Rock Mechanics IV
GeoE 151-152-153 — Special Geo-Engineering Problems
MinE 156 — Gravity Flow of Fragmented Materials
GeoE 160 — Geology and Technology of Nonmetallic Rocks and Minerals
MinE 171, 171A, 172, 173 — Fluid Flow Through Porous Media
CE 157 — Slope Stability
CE 159 — Bearing Capacity
Geo 2 or 22 — Historical Geology
Geo 64 — Introductory Sedimentology and Stratigraphy
Geo 115 — Geomorphology
Geo 120 — Structural Geology
Math 147, 148, 149 — Vector Analysis; Differential Equations; Determinants and Matrices
(or) Math 107A-B-C — Advanced Calculus

B. For students with a principal interest in oil or mineral exploration, mining geology, etc.

MinE 112 — Principles of Mineral Engineering II: Development and Exploitation
MinE 120 — Mine and Mill Plant Engineering
MinE 141 — Mineral Economics I
MinE 155 — Surface Mining Engineering
GeoE 160 — Geology and Technology of Nonmetallic Rocks and Minerals
GeoE 180 — Geochemical Exploration
GeoE 185 — Selected Topics in Mineral Exploration
MinE 106, 107 — Principles of Process Metallurgy I, II
MinE 114, 115 — Mineral Processing I, II
MinE 165 — Techniques of Mineral Processing Research III
MinE 171, 171A, 172, 173 — Fluid Flow Through Porous Media I, II, III
Geo 120 — Structural Geology
Geo 155, 156 — Mineral Deposits
Geo 157 — Mineral Fuel Deposits
Geo 140, 141 — Mineral Systems I, II
Math 33 — Calculus VI
PCh 107-108 — Elementary Physical Chemistry

Industrial Engineering

(Department of Mechanical Engineering)

Professional training in industrial engineering is offered through an industrial engineering option in mechanical engineering. This option leads to the degree of bachelor of mechanical engineering, B.M.E.

In addition to the prescribed courses, sufficient approved electives must be taken to complete a total of at least 204 credits for graduation. Students must submit a petition for entrance into the industrial engineering option.

The industrial engineering curriculum offers the student an opportunity to learn those scientific and engineering principles which deal with the optimum utilization of men, materials, and equipment.

The industrial engineer studies product designs to adapt them for economic production, determines an optimum system of necessary operations, selects the most economical production equipment and tooling and develops effective work methods and measurements. He must learn the fundamental concepts associated with developing inventory and production controls, establishing production standards, estimating and comparing alternative costs of new operations, and administering wage incentives and cost reduction programs. The industrial engineer is also concerned with the development and analysis of the optimum layout of industrial plants together with systems of materials handling.

Today the industrial engineer should have a knowledge of the potential usefulness of the high speed digital computer as a tool in engineering research, industrial development and control. Industrial statistics and engineering mathematics together with engineering economics are fundamental to industrial engineering. Formulating problems, weighing the objectives, constructing mathematical models, obtaining analytical and numerical solutions, and making decisions are fast becoming the industrial engineer's responsibilities. In fact, by applying his engineering training and his appreciation of the basic managerial problems of an enterprise, the industrial engineer has become the key adviser to managers constantly faced with a variety of decisions to be made.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering.

Second Year

See section on Mechanical Engineering for recommended program.

UPPER DIVISION

Third and Fourth Years

See section on Mechanical Engineering for recommended integration with other required courses.

	Credits
ME 99 — Introduction to Engineering Analysis	3
IE 100 — Industrial Engineering Analysis	3
IE 110 — Introduction to Work Analysis	4
IE 130 — Introduction to Operations Research	4
IE 172 — Manufacturing Cost Analysis	3
IE 120 — Probability Models in Industrial Engineering and Operations Research	3
Industrial engineering electives	12
Electives (see Index for Liberal Education Category Requirements)	

GRADUATE STUDY IN INDUSTRIAL ENGINEERING

Students who have received a Bachelor's degree in any engineering area may be admitted to graduate study majoring in industrial engineering provided they meet the entrance requirements of the Graduate School. Both the Ph.D. and master of science degrees are offered. Candidates will be expected to complete, either as undergraduates or as graduate students, adequate preparation in undergraduate subjects and in the sciences fundamental to industrial engineering. The M.S. degree in industrial engineering is offered under both Plan A and Plan B.

Mechanical Engineering

(School of Mechanical and Aerospace Engineering)

A 4-year curriculum is offered which leads to the degree of bachelor of mechanical engineering, B.M.E.

In addition to the prescribed courses, sufficient electives must be taken to complete a total of at least 204 credits for graduation.

The mechanical engineering curriculum is based upon the physical sciences and mathematics and is concerned with the adaptation of materials and energy to the useful purposes of mankind. Consideration is given to the economic and social factors involved. The areas include heat transfer and thermodynamics, power and propulsion, industrial engineering, environmental control, the design of machines and systems and their control, and graphical communications.

There is an industrial engineering option in mechanical engineering which offers an opportunity to learn those scientific and engineering principles which deal with economic production, optimum systems of necessary operations, selection of most economical production equipment and tooling, and development of effective work methods and measurement. For those who wish to pursue graduate work in industrial engineering, a separate graduate major leading to the M.S. or Ph.D. degree is offered.

An engineering intern program is available during the last 2 years of study upon application and acceptance. This provides practical work experience in conjunction with regular courses and laboratory work through cooperation with nearby industrial concerns.

An electrical engineering concentration program is offered in conjunction with the regular mechanical engineering curriculum and provides for additional course work in electrical engineering. The program allows the mechanical engineering student to gain more depth in various areas of electrical technology in preparation for numerous industrial assignments and advanced work utilizing this combination. Details of the program are given in the section on curriculum requirements for mechanical engineering.

An honors program is also offered in mechanical engineering for students with a high grade point average. The program provides for more flexibility in the selection of course work while maintaining a strong core in engineering fundamentals. With the additional elective freedom, the student can obtain more depth in specific areas of interest or build a basic background in preparation for graduate study. Qualifications include a 3.00 GPA in Lower Division work and approval of a proposed program of study by the Mechanical Engineering Honors Committee. To obtain maximum benefit, plans should be made prior to the third year in school. Further details can be obtained from the departmental office (125 ME).

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering.

Second Year

	Credits — f	w	s
Math 31-32 — Calculus IV, V	5	5	..
GeCh 14-15 — General Principles of Chemistry (see Note below)	4	4	..
Phys 23T, 50T — General Physics; Modern Physics (see Note below)	4	..	4
Phys 23A, 50A — Physics Laboratory (see Note below)	1	..	1
MM 35, 37, 36 — Statics; Deformable Body Mechanics; Dynamics	4	4	4
ME 99 — Introduction to Engineering Analysis	..	..	3
Electives (see Index for Liberal Education Category Requirements)	0	3	6
Total credits	18	16	18

Note — It may be necessary or appropriate to rearrange scheduling of general chemistry, physics and electives depending on class scheduling bulletins for 1969 through 1971. Mechanical engineering students are required to satisfy the Institute of Technology minimum liberal education requirements.

UPPER DIVISION

Third Year

	Credits — f	w	s
ME 22, 23 — Analysis of Mechanism Systems; Mechanical Engineering Systems Analysis	4	4	..
ME 30A-31A — Thermodynamics	4	4	..
ME 33-34-35 — Measurements Laboratory I, II, III	2	2	2
EE 30-31 — Circuit Analysis	3	3	..
EE 30A-31A — Electrical Engineering Laboratory	1	1	..
CE 101A — Fluid Mechanics	..	4	..
ME 133 — Heat Transmission	..	..	3
ME 24 — Optimum Design of Mechanical Elements	..	..	3
IE 100 — Industrial Engineering Analysis	3	..	..
MetE 56 — Physical Metallurgy	..	..	3
Electives (see Index for Liberal Education Category Requirements)	..	..	6
Total credits	17	18	17

Fourth Year

		Credits — f	w	s
ME 125 — Machine Design Laboratory ME 159 — Power and Propulsion Laboratory ME 169 — Psychrometrics and Air Conditioning Laboratory	(any order)	2	2	2
ME 146A — An Introduction to Combustion and Propulsion ME 160A — Thermal Environmental Engineering ME 170 — Manufacturing Processes	(any order)	4	4	4
ME 134 — Thermodynamics of Fluid Flow ME 197 — System Analysis and Control	(any order)	3	3	..
ME 191-192-193 — Mechanical Engineering Design		2	2	2
Electives (see statement below)		6	6	9
	Total credits	17	17	17

All students are required to have elective courses approved by their adviser. Technical electives, unless approved by petition, must be selected from Upper Division courses offered in engineering, mathematics, or the physical sciences. Ordinarily, 14 technical electives and 30 liberal education electives in addition to 9 credits of English are required. Additional free electives should be chosen to total the 204 credits required for graduation. Changes in course requirements, except those subsequently approved in faculty action or in department notices must be approved by petition.

P-N Course Policy — All "required" courses must be taken on an A-F basis. Any elective course may be taken on P-N option, consistent with the general requirements of the Institute of Technology.

INDUSTRIAL ENGINEERING OPTION

Mechanical engineering training with specialization in industrial engineering is provided by this option. Students who follow this option are also eligible to apply for the engineering intern program. For further descriptive information, see Industrial Engineering section.

First Year

See first-year curriculum for College of Engineering.

Second Year

See second-year curriculum for mechanical engineering.

UPPER DIVISION

Third Year

	Credits — f	w	s
ME 33-34-35 — Measurements Laboratory I, II, III	2	2	2
ME 30A — Thermodynamics	4	..	..
ME 22 — Analysis of Mechanism Systems	4	..	..
IE 100 — Industrial Engineering Analysis	3	..	..
MetE 56 — Physical Metallurgy	..	3	..
ME 170 — Manufacturing Processes	..	..	4
IE 130 — Introduction to Operations Research	4	..	..

	f	w	s
IE 172 — Manufacturing Cost Analysis	..	..	3
IE 110 — Introduction to Work Analysis	..	4	..
IE 120 — Probability Models in Industrial Engineering and Operations Research	..	..	3
CE 101A — Fluid Mechanics	..	4	..
Elect one sequence of: ME 23 — Mechanical Engineering Systems Analysis; ME 24 — Optimum Design of Mechanical Elements (or) ME 31A — Thermodynamics; ME 133 — Heat Transmission	..	4	3
Electives (see Index for Liberal Education Category Requirements)	..	..	3
Total credits	17	17	18

Fourth Year

	Credits — f	w	s
ME 191-192-193 — Mechanical Engineering Design	2	2	2
ME 197 — System Analysis and Control	3	..	..
EE 30-31 — Circuit Analysis	3	3	..
EE 30A-31A — Electrical Engineering Laboratory	1	1	..
Take remaining courses of: ME 23 — Mechanical Engineering Systems Analysis; ME 24 — Optimum Design of Mechanical Elements (or) ME 31A — Thermodynamics	..	4	3
Industrial engineering electives	3	3	6
Electives (see Index for Liberal Education Category Requirements)	3	..	3
Technical electives	3	3	3
Total credits	18	16	17

All students are required to have their elective courses approved by their adviser. The electives must be sufficient to complete a total of at least 204 credits for graduation.

ENGINEERING INTERN CURRICULUM

A mechanical engineering Intern Program, formerly known as the cooperative work-study program, is available during the last 2 years of study. Completion of the major part of the Lower Division academic curriculum and a minimum GPA of 2.00 is required for admission. Special applications must be made prior to January 1 of the sophomore year. The program provides applied engineering training during alternate quarters of industrial assignments with selected well-known industries. The student is registered in the University during work periods, and at all times is considered a regular full-time University student.

The awarding of a B.M.E. will require the satisfactory completion of all the basic required University work as designated in the regular mechanical engineering curriculum including 4 alternate quarters of supervised industrial experience.

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

ELECTRICAL ENGINEERING CONCENTRATION

The program follows the same general requirements as the regular mechanical engineering program with the following changes:

Exemptions:

ME 134, ME 197 — 3 credits each — only one required
ME 146A, ME 160A — 4 credits each — only one required
ME 125, 159, 169 — 2 credits each — only one required

Additions:

Math 33 or 60A or equiv — 3 to 5 credits
EE 64-65, 84-85 — 12 credits

Students wishing to enter the program should complete an intent form available in the Mechanical Engineering office, 125 ME. The program should be started during the third year, except that student should consider taking Math 33 in the spring quarter of the sophomore year.

COMBINED CURRICULA OF MECHANICAL ENGINEERING AND LAW

These curricula enable the student to obtain two degrees, one in the Institute of Technology and one in the Law School, in a period of approximately 7 years. To be eligible for admission to the Law School, the student must complete a 4-year mechanical engineering program and qualify for the Bachelor's degree. Then the regular law program will be followed. This leads to the degree of bachelor of laws.

GRADUATE STUDY IN MECHANICAL ENGINEERING

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

Metallurgy-Materials Science

(School of Mineral and Metallurgical Engineering)

A 4-year curriculum is offered which leads to a degree of bachelor of metallurgical engineering, B.Met.E. A minimum of 197 credits is required for graduation.

The metallurgist and materials scientist study the structure and properties of all kinds of materials (metals, nonmetals, glasses, ceramics, plastics) in order to use these materials wisely and efficiently in specific applications. Emphasis is placed upon an understanding of the fundamentals of chemical reactions between solids, liquids, and gases and upon the atomic structure of solids and the relation of that structure to the properties. All types of solid materials are studied in the program because the metallurgist and materials scientist make decisions about the best possible material for a specific application. Properties studied include the structure of the material, mechanical, and electrical characteristics.

Because of their unique training the materials scientist and metallurgist are in great demand in many industries such as the basic metals and ceramics industries, computers, aerospace, electronics, and chemical processing. They are employed in research, development, and plant operation. With further advanced studies, excellent teaching opportunities are available. The demand for materials-oriented specialists is also rapidly increasing because many technological innovations are limited not by design considerations, but by the lack of suitable materials to carry out new ideas. In fact, the need for materials-oriented people has expanded so much in recent years that there are now twice as many job openings that go unfilled as are filled by materials-trained graduates. The field continues to expand at an increasingly rapid rate and it therefore offers many challenges for the future.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering.

Second Year

	Credits — f	w	s
Math 31-32 — Calculus IV, V	5	5	..
Mathematics elective (ME 99, Math 33 or other)	..	..	3-5
Phys 23T, 50T — General Physics; Modern Physics	4	4	..
Phys 23A, 50A — Physics Laboratory	1	1	..
MM 35 — Statics	4	..	..
GeCh 14-15 — General Principles of Chemistry	4	4	..
GeCh 6 — Principles of Solution Chemistry (or) OrCh 16 — Carbon Compounds	..	..	4
MM 37 — Deformable Body Mechanics	..	..	4
MetE 2 — Introduction to Materials	..	..	2
Liberal education electives (see Index for Category Requirements)	..	3	3
Total credits	18	17	16-18

UPPER DIVISION

Third Year

	Credits — f	w	s
MetE 101-102-103 — Introduction to Science of Materials	3	3	3
PCh 101, 102, 104 — Physical Chemistry	4	4	4
MetE 104 — X Rays	3	..	..
MetE 105 — Quantitative Metallography and Electron Microscopy	..	3	..
Electives	6	6	9
Total credits	16	16	16

Fourth Year

	Credits — f	w	s
MetE 110 — Physical Metallurgy Laboratory	..	..	3
MetE 153-154-155 — Solidification and Transformation of Metals and Alloys	3	3	3
MetE 180-181 — Thermodynamics and Kinetics of the Solid State	3	3	..
MetE 182 — Theory of the Structure of Metals and Alloys	..	..	3
Phys 146 — Vacuum Tube and Transistor Circuits	4	..	..

Phys 148 — Applications of Electronic Circuits	..	4	..
Electives	6	6	6
Total credits	16	16	15

Mineral Resources Engineering

(School of Mineral and Metallurgical Engineering)

MINING AND PETROLEUM ENGINEERING PRODUCTION PROCESSES MINERAL AND METAL EXTRACTIVE PROCESSES

A 4-year curriculum is offered that leads to the degree of bachelor of mineral engineering, B.Min.E. A total of 203 credits, including field trips, is required for graduation.

Mineral resources engineering blends into a unified and balanced program the disciplines of (1) mineral and petroleum production processes, and (2) mineral and metal extractive processes. Through the proper selection of technical electives a student may broaden and deepen curriculum preparation in the area of his principal interests. The field is closely allied with geo-engineering.

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

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

The education of the mineral resources engineer is based on scientific and engineering principles to prepare him for the varied demands of his profession and yet not confine him to a narrow specialty. The preparation is broad, not only in the basic and allied engineering sciences but also in geology and economics. The two broad areas of study overlap somewhat as the production engineer and the extractive engineer must be knowledgeable of each other's specialties. Common to both study areas is mineral economics, which illuminates the probabilities of success or failure of a mineral venture. These subjects deal with supply and demand of mineral commodities, examination and evaluation of mineral properties and projects, and problems of financing, depletion, and conservation, among other things.

Transfer Students — Students from junior colleges, state colleges, liberal arts colleges, and branches of the University of Minnesota may transfer to the School of Mineral and Metallurgical Engineering and continue academic work toward the degree of B.Min.E. Students will receive transfer credit for suitable course work taken prior to entering the Institute of Technology, and study programs to suit individual curriculum requirements will be arranged with a departmental adviser.

Faculty Adviser — The undergraduate student is assigned a member of the faculty as his adviser who will assist the student in selecting courses for his curriculum. The adviser will serve as a consultant during the student's scholastic career.

Electives — A student should consider the areas of his principal interests and discuss with his adviser a selection of technical electives best suited to serve his needs and promote his interests. Those who intend to take graduate work directed toward research and teaching are encouraged to elect courses in mathematics, chemistry, mechanics, and fluid dynamics. Students interested in engineering management should elect courses in industrial engineering, economics, and business.

Undergraduate Job Opportunities — The research programs in the department provide job opportunities for stimulating engineering and research experience, and for developing scientific interest and motivation. Summer job opportunities are abundant in the mines, oil fields, and metallurgical plants throughout the country.

Master of Engineering Program — The field of mineral resources engineering sponsors graduate work toward the advanced degrees of M.S., Ph.D., and M.Min.E. The latter program is designed for those Bachelor degree holders interested in design, operations, or management. The candidate should have a 2.50 GPA. It is urged that any undergraduate considering advanced work should direct his fourth-year course work with that objective in mind.

LOWER DIVISION

First Year

See first-year curriculum for College of Engineering.

Second Year

	Credits — f	w	s
Math 31-32 — Calculus IV, V	5	5	..
Introductory course in computer programming	..	..	1-4
Phys 23T, 50T — General Physics; Modern Physics	..	4	4
Phys 23A — General Physics Laboratory	..	1	..
GeCh 14-15 — General Principles of Chemistry	4	4	..
MM 35, 37 — Statics; Deformable Body Mechanics	4	4	..
ME 99 — Introduction to Engineering Analysis	..	..	3
MinE 1 — Mineral Engineering Laboratory	..	..	1
Elective (see statement following 4th year)	..	..	3
Liberal education requirement (see statement following 4th year)	3	..	3
Total credits	16	18	15-18

UPPER DIVISION

Third Year

	Credits — f	w	s
GeoE 131 — Rock Mechanics I	..	3	..
MinE 106, 107 — Principles of Process Metallurgy I, II	3	4	..

GeoE 111 — Geological Exploration	3	..	..
MinE 112 — Principles of Mineral Engineering–Development and Exploitation	..	3	..
MinE 114 — Mineral Processing I	..	..	3
MinE 120 — Mine and Mill Plant Engineering I	..	..	3
MinE 137 — Computer Applications in Mineral Engineering	..	..	3
CE 61A — Surveying Engineering	3	..	..
CE 101A — Fluid Mechanics	..	..	4
Geo 11 — Introductory Physical Geology	5	..	..
Geo 62 — Introductory Mineralogy	..	5	..
PCh 107, 108 — Elementary Physical Chemistry	3	3	..
Electives (see statement following 4th year)	..	..	3
Total credits	17	18	16

MinE 139 — Engineering Field Study, 2 weeks .... 3 credits

Fourth Year

	Credits — f	w	s
MinE 115, 116 — Mineral Processing II, III	3	3	..
MinE 117-118 — Metallurgical Engineering Design (or) MinE 144, 145 — Mineral Engineering Design	..	2	4
MinE 121 — Mine and Petroleum Plant Engineering II	3	..	..
MinE 141 — Mineral Economics I	..	3	..
MinE 142 — Mineral Economics II	..	..	0-3
(or) MinE 155 — Surface Mining Engineering	3-0	..	..
Electives (see statement following 4th year)	3-6	6	8-5
Liberal education requirement	6	3	3
Total credits	18	17	15

ELECTIVES

All students are required to have elective courses approved by their adviser. The technical electives preferably should be selected from the following lists. Ordinarily 24 technical electives and 30 liberal education electives (in addition to the 9 credits of English) are required.

A. For those with principal interest in the *Mining and Petroleum Engineering Production Processes*

GeoE 132, 133, 134 — Rock Mechanics II, III, IV
MinE 90-94 — Industrial Employment
MinE 113 — Earth Fluids and Flow
MinE 122 — Mine Plant Engineering III
MinE 142 — Mineral Economics II
MinE 155 — Surface Mining Engineering
MinE 171-173 — Fluid Flow Through Porous Media I, II, III
Geo 64 — Introductory Sedimentology and Stratigraphy
Geo 65 — Introductory Field Geology
Geo 120 — Structural Geology
Geo 155, 156 — Mineral Deposits I, II
Geo 157 — Mineral Fuel Deposits
Math 33 — Calculus VI
MM 36 — Dynamics

B. For those with principal interest in the *Mineral and Metal Extractive Processes*

MinE 90-94 — Industrial Employment
MinE 108 — Metallurgical Unit Processes
MinE 122 — Mine Plant Engineering III
MinE 160, 161 — Hydrometallurgy I, II

MinE 162 — Electrical and Magnetic Separation of Minerals
MinE 163, 164, 165 — Techniques of Mineral Processing Research I, II, III
MinE 166, 167, 168 — Physical Chemistry of High Temperature Metallurgical Reactions I, II, III
MinE 181 — Special Problems in Extractive Metallurgical Engineering
Math 33 — Calculus VI
MetE 56 — Physical Metallurgy
MetE 161 — Corrosion of Metals

SCHOOL OF ARCHITECTURE AND LANDSCAPE ARCHITECTURE

The curriculum of the School of Architecture and Landscape Architecture is being revised. Students enrolling in the School of Architecture and Landscape Architecture in the fall of 1969 should consult their advisers as they will be responsible for the new curriculum to be announced in a supplemental bulletin which will be published in the spring of 1970.

Architecture

The places in which men live, work, play, aspire, and worship are largely the product of their own devising. This process of devising, molding, and shaping the physical environment is the practice of architecture.

The architect is concerned with the places in which men live: small buildings and large building complexes, neighborhoods and public spaces, and, in the broadest sense, cities and their hinterland. For the city is the sum total of man's ability to respond to the demands of society; it reflects his ability to relate and coordinate the many and diverse individual parts into a coordinated whole.

The architect seeks to conceive a total environment which will encourage and heighten man's activities and aspirations. The architect is concerned with comfortable and convenient housing, functional factories, office buildings, schools, hospitals, and shopping centers. In each of these individual works he endeavors to establish sensitive relationships and integration to the total environment.

Architecture is an environmental art and science and the demands upon it are well defined:

1. The building or place must serve the purpose for which it was built; it must be useful.

2. It must be soundly constructed; its structure must be firm and its materials and equipment suitable for their use.

3. It must be beautiful to behold.

The *usefulness* of a building or place is a vital measure of architecture today. Since society determines the purpose and need for a building, it is important that the arrangement of spaces encourages and fosters the intended activities and use. In a school building for instance, the arrangement of spaces should be conducive to the learning process. In a science classroom the kind of demonstration or experiment to be conducted must be considered. Will instruction require the use of visual teaching aids, blackboards, or writing desks?

Such a variety of considerations affect the utility of every building. It is the architect's assignment to study and analyze each of the functions and give them suitable accommodations in space and to order them so that they relate appropriately to each other. For usefulness involves not only each minute part of a building, but it involves also the sum of those parts and the way in which they interact.

Soundness and firmness in architecture require technical skill and knowledge in the devising of a structure or framework into which the spaces or rooms may be fitted. They also require the devising of techniques of fitting things together — the appropriate joinery of the elements and materials; and they require the selection of each material such that it "belongs" to, and contributes to the total effect of the building.

Beauty in architecture is among the more elusive of its requirements. It is in delight to the eye that architecture reaches its highest performance as an art. Through vision man measures space and furnishings, and building masses and form. His eye follows the patterns of light and shade, races over the eloquent rhythmic surfaces and ordered detail, and encompasses those aspects of the environment which enrich the meanings of a building. Buildings are made by man for men, and their nature and size in relation to man can be fully experienced only in the real-life situation, in the design or arrangement of elements, or in the expression and meaning of a building.

Thus, the architect gives the physical expression to the ideas and aspirations of the society of which he is a part. His imprint upon the environment makes him a part of today's problems and potentials: dramatic population growth with increasingly higher proportions of the young and the very old; decreasing requirements at productive work and expanding amounts of free time for intellectual endeavors, recreation, and leisure; scientific and technological advances which offer promise of contributing to a richer, fuller life; unchecked obsolescence and decay — social as well as physical — in the inner city; mediocrity in much of the sprawling suburban hinterlands; and pollution of the land, water, and air which are man's most precious heritage.

These and many other aspects of the man-made environment confront society today. And they are of the essence of the situations with which the architect will be concerned in the remaining 30 years of this century.

Five-Year Curriculum — Leads to the degree of bachelor of architecture, B.Arch. This curriculum requires a minimum of a year of college work preparatory to 4 years of study in the School of Architecture. It is intended for students who expect to practice architecture in any of its recognized phases. When supplemented by practical experience, it qualifies graduates for admission to architectural registration examinations according to the laws of the various states.

Four-Year Curriculum — Leads to the degree of bachelor of arts, B.A., with a major in architecture. This curriculum is intended for students who wish to combine some study of architecture with general education. It does not constitute terminal professional training. It does, however, provide an advantageous approach to professional training in specialized fields of architecture, city planning, landscape architecture, and decorative, industrial, or interior design. Students following this curriculum are enrolled in the College of Liberal Arts. For further details, see the *College of Liberal Arts Bulletin.*

Six-Year Curriculum — Represents a combination of the 4-year curriculum and the 5-year curriculum. It leads, after approximately 4 years of study, to the degree of bachelor of arts, B.A., with a major in architecture; and finally to the degree of bachelor of architecture, B.Arch., upon completion of additional work in the School of Architecture. For further details, see course outline below and the *College of Liberal Arts Bulletin.*

In addition to the above, the School of Architecture offers work on the graduate level leading to the degree of master of architecture, M.Arch. For details, see the *Graduate School Bulletin.*

Admission Procedures — Approval of the School of Architecture and of the dean of the Institute of Technology is required for enrollment as a candidate for the B.Arch. degree, or as a candidate for the B.A. degree with a major in architecture. A prerequisite for such approval is:

Five-year curriculum — Completion of 1 year of college work (see first-year program of following section).

Four-year curriculum — Completion of 2 years of college work required for entrance to the Upper Division of the College of Liberal Arts as stated in its bulletin.

Six-year curriculum — Completion of 4 years of college work as required for the B.A. degree with a major in architecture in the College of Liberal Arts.

Upon completion of the prerequisite work, application shall be made to the School of Architecture for enrollment in the desired curriculum. Application forms (AR 110) may be obtained from the School of Architecture or from the Office of Admissions and Records. *These should be submitted to the Office of Admissions and Records not later than June 1 preceding the beginning of the academic year for which admission is being sought.* Admission to beginning architectural design (Arch 81) is permitted only in the fall quarter.

Approval of admission will be based on a consideration of (a) the student's scholastic standing in high school and on previous college work, (b) his maturity and experience, (c) his professional aptitude and objectives, and (d) the work space and instructional facilities of the School of Architecture. Prospective students are urged to consult advisers in the School of Architecture, 110 Architecture Building.

FIVE-YEAR CURRICULUM

The core of study is a sequence of architectural design courses requiring 4 years. These provide cumulative experience with a large number of design problems involving an evaluation of pertinent factors of site, climate, purpose, and social setting; they provide scope for the application of the student's growing knowledge of materials and building techniques as well as his judgment and creative skill. Field inspection trips are included.

Specialization in various phases of architecture is available to students of superior ability. This is accomplished by optional problems and course substitutions in Arch 121, 122, and 123.

Before enrolling in Arch 123, each student is required to present evidence of a minimum of 800 hours of practical experience outside of classwork. Such experience would be preferably in an architect's office.

In addition to the required courses listed below, sufficient approved electives must be taken to complete a total of at least 253 credits. The following program is typical for students who have been admitted to the Institute of Technology with acceptable credits in mathematics and English and who maintain a normal rate of progress after admission.

First Year

	Credits — f,	w,	s
Engl 1-2-3 — Freshman English	3	3	3
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Phys 1-2-3; 1A-2A-3A — Introductory Physics; Laboratory	4	4	4
Arch 21 — Architectural Theory and History	3	..	..
Electives (see Index for Liberal Education Category Requirements)	..	3	3
Total credits	15	15	15

This first-year pre-architectural work may be met by presentation of credits for comparable work in the University of Minnesota College of Liberal Arts or in another educational institution.

Second Year

	Credits — f,	w,	s
Arch 81-82-83 — Architectural Design	6	6	6
Arch 51, 52, 53 — History of Architecture	3	3	3
ArtS 23A, 24A, 25A — Drawing and Painting I (C.L.E. Category 4)	2	2	2
MM 92, 93 — Statics and Solid Mechanics for Architects	..	4	4
Electives (see Index for Liberal Education Category Requirements)	5	3	3
Total credits	16	18	18

An additional 3 credits of electives may be substituted for Arch 51, 52, 53, or 54.

Third Year

	Credits — f,	w,	s
Arch 91-92-93 — Architectural Design	6	6	6
Arch 54, 55, 56 — History of Architecture	3	3	3
Arch 71-72-73 — Building Technology	4	4	4
ArtS 60A-61A-62A — Drawing and Painting II (C.L.E. Category 4)	2	2	2
CE 78-79-80 — Elementary Structural Design	3	3	3
Total credits	18	18	18

Fourth Year

	Credits — f, w, s		
Arch 111-112-113 — Architectural Design	7	7	7
Arch 74-75-76 — Building Technology	4	4	4
Arch 115-116 — Structure and Form in Architecture	3	3	..
Arch 133 — Planning	..	..	3
Electives	3	3	3
Total credits	17	17	17

Fifth Year

	Credits — f, w, s		
Arch 121-122 — Architectural Design	9	9	..
Arch 123 — Thesis	..	..	12
Arch 131, 132 — Planning	3	3	..
Arch 126 — Professional Relations	..	..	3
Electives	3	3	..
Total credits	15	15	15

FOUR-YEAR CURRICULUM

First and Second Years

The first-year and second-year work is taken in the Lower Division of the College of Liberal Arts as outlined in its bulletin. The following requirements must be included for admission to the major in architecture in the Upper Division: high school or college equivalents of higher algebra, solid geometry, Phys 1-2-3, 1A-2A-3A, ArtS 23A-24A-25A.

Third and Fourth Years

During the third and fourth years the student registers in the Upper Division of the College of Liberal Arts as a major in architecture. The major sequence must include the following:

	Credits — f, w, s		
Arch 81-82-83 — Architectural Design	6	6	6
Arch 91-92-93 — Architectural Design	6	6	6
Arch 51, 52, 53 — History of Architecture	3	3	3

See the *College of Liberal Arts Bulletin* for complete Upper Division requirements.

SIX-YEAR CURRICULUM

First and Second Years

The first-year and second-year work is taken in the Lower Division of the College of Liberal Arts as outlined in that bulletin. The following requirements must be included as prerequisites for admission to the major in architecture in the Upper Division and completion of the professional work in the last 2 years.

	Credits — f, w, s		
Math 15 — College Algebra	5	..	..
Math 42-43 — Analytic Geometry and Calculus I, II	..	5	5
Phys 1-2-3; 1A-2A-3A — Introductory Physics; Laboratory	4	4	4
Arch 21 — Architectural History and Theory	3	..	..
ArtS 23A, 24A, 25A — Drawing and Painting I (C.L.E. Category 4)	2	2	2

Approved electives to make a minimum of 90 credits. See Index for Liberal Education Category Requirements.
Prerequisites: High school algebra, solid geometry and trigonometry. If high school trigonometry is not offered, Math T must be taken prior to Math 15.

Third and Fourth Years

During the third and fourth years the student registers in the Upper Division of the College of Liberal Arts as a major in architecture. The following courses should be included:

	Credits — f	w	s
Arch 81-82-83 — Architectural Design	6	6	6
Arch 91-92-93 — Architectural Design	6	6	6
Arch 51, 52, 53 — History of Architecture	3	3	3
ArtS 60A-61A-62A — Drawing and Painting II (C.L.E. Category 4)	2	2	2
MM 92, 93 — Statics and Solid Mechanics for Architects	..	4	4

Approved electives to make a minimum total of 180 credits acceptable for the B.A. degree.

One of the following sequences must also be included in the third and fourth years in order to permit completion of the curriculum in 6 years. Credit for such, however, may not be counted in the 180 credits required for the B.A. degree.

	Credits — f	w	s
CE 78-79-80 — Elementary Structural Design	3	3	3
Arch 71-72-73 — Building Technology	4	4	4

See the *College of Liberal Arts Bulletin* for complete Upper Division requirements.

Fifth and Sixth Years

During the fifth and sixth years the student registers in the Institute of Technology as a candidate for the B.Arch. degree. Before doing so, he must obtain the approval of the School of Architecture as a candidate for the B.Arch. degree. The following courses should be included

	Credits — f	w	s
Arch 111-112-113 — Architectural Design	7	7	7
Arch 121-122 — Architectural Design	9	9	..
Arch 123 — Thesis	..	..	12
Arch 54, 55, 56 — History of Architecture	3	3	3
Arch 71-72-73 — Building Technology	4	4	4
Arch 74-75-76 — Building Technology	4	4	4
Arch 115-116 — Structure and Form in Architecture	3	3	..
Arch 126 — Professional Relations	..	..	3
Arch 131, 132, 133 — Planning	3	3	3
CE 78-79-80 — Elementary Structural Design	3	3	3

Approved electives to make a minimum total of 291 credits for the two degrees.

Landscape Architecture

Goals and Concerns of the Profession — The problems of relating man and land, each with their complex needs, is the general focus of the professional design field of landscape architecture. Within this focus the landscape architect is specifically concerned with the quality of experience in the exterior environment which results for man through modification of lands for specific human uses. This focus on quality does not merely imply a concern for the ornamental aspects of environment, but rather the total visual-functional interrelationship of experiencing our exterior environment. In detail, he is concerned with design of the relationships between a specific site with its individual qualities of terrain, soil, climate, vegetation, orientation, and views, and the program for development with its proposed facilities, use areas, and circulation needs. Thus he attempts to secure the most desirable relationships between open spaces and buildings, walks and roads, planting and landforms, in order to best resolve human requirements of utility and beauty in the use of land.

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

Persons interested in entering the field should have a strong interest in nature and greatly enjoy observing the patterns and qualities of the landscape. A basic desire to put concepts and thoughts into graphic form is a further strong indication of interest in the profession.

Objectives of the Curriculum — The course of study in general is designed to provide the student with a broad educational background together with technical studies essential for the professional practice of landscape architecture.

Technical studies include training in the applied land sciences: courses in geology, soils, climatology, ecology, civil engineering, and horticulture. Liberal arts studies in psychology, sociology, geography, and history allow the exploration of how man relates to his environment. Students in the program are stimulated to become critical observers in terms of the quality of experience in the exterior environment; to develop systematic problem solving techniques; and to develop techniques for portraying concepts with graphically clear communicative skill.

This training in general is aimed at providing the student with thought capacity, leadership ability, flexibility, and an understanding of the techniques and possibilities of his own profession and its relation to other disciplines. In this respect, the professional degree is excellent background for further study in city and regional planning as well as landscape architecture.

Curriculum Alternatives — The program for the professional degree in landscape architecture may be approached via three alternative avenues. These programs are a 5-year curriculum taken wholly in the Institute of Technology, a 6-year curriculum taken both in the College of Liberal Arts and in the Institute of Technology, and a 5-year curriculum taken both in the Institute of Agriculture and the Institute of Technology.

All three programs lead to a professional degree in landscape architecture (B.L.A.). The 5-year program leads directly to the professional degree and provides the student with intensive study in design and land and landscape development techniques. The 6-year curriculum allows a bachelor of arts degree with a major in landscape architecture as an intermediate degree. Those students choosing this avenue will receive greater training in the behavioral and natural sciences. The 5-year program given through the Institute of Agriculture and the Institute of Technology allows a bachelor of science in landscape design and environmental planning as an intermediate degree. Those students choosing this avenue will receive greater emphasis on the applied plant sciences and recreation resource planning. The 4-year degree in the College of Liberal Arts and the Institute of Agriculture are not professional degrees in landscape architecture but they provide the student with beginning training toward the professional degree (B.L.A.).

Requirements for the professional degree are being revised. Interested students should check with faculty in 110 Architecture on these requirements.

Five-Year Curriculum — The program is organized to provide a highly concentrated approach to the professional degree — bachelor of landscape architecture. Its science and technical requirements parallel that of the 6-year program but it allows only a minimum of credits for liberal arts courses and technical electives. The initial year of study is devoted to general University courses which serve as preparation to the remaining 4 years of professional training within the curriculum. This training supplemented with practical experience qualifies the student for professional practice.

In addition to the required courses listed below, the student must satisfy the basic general curricular requirements as specified for all students in the Institute of Technology, as a part of nontechnical group requirements. The humanities, psychology, and sociology sequences are strongly recommended as courses to satisfy this requirement. In addition, a basic course in speech technique is suggested as a part of the courses taken as nontechnical electives. It is also strongly recommended that a student take a year of high school chemistry before applying for entry to the Institute of Technology. A basic knowledge of chemistry is vital for much of the advanced work in the program.

Before enrolling in LA 123 each student is required to present evidence of a minimum of 800 hours of practical experience outside of classwork. At least 400 of these hours must be spent in landscape construction or in a landscape nursery. At least an additional 400 hours must be spent in an office of a professional landscape architect.

Three months' travel experience may be substituted for one-half the work experience requirement. Travel proposals must be reviewed and approved by an instructor before departure and a written-graphic review of projects visited must be submitted following the travel before this substitution can be effected.

In addition to the required courses, sufficient approved electives must be taken to complete a total of at least 253 credits. The following program is included to illustrate a typical course sequence for students who have been admitted to the Institute of Technology with acceptable credits in mathematics and English and who maintain a normal rate of progress after admission.

Admission Procedures — Upon completion of the prerequisite requirements, application shall be made to officially enter the School of Architecture. This should be done by completing form AR 110 available at the School of Architecture or from the Office of Admissions and Records. *These should be submitted not later than June 1 of the year during which the student wishes to begin course work within the school.* Admission to beginning design (Arch 81) is permitted only in the fall quarter. The prerequisite requirements are met by completing the first year of the 5-year degree program.

Approval of admission will be based on consideration of the following: (1) student's scholastic standing in high school and on previous college work; (2) his maturity and experience; (3) availability of work space and instructional facilities.

Students who wish to apply for advanced standing within the program are requested to bring a brochure of their work and grade transcript to discussions with the advisers in the School of Architecture and Landscape Architecture.

First Year

	Credits — f	w	s
Engl 1-2-3 — Freshman English	3	3	3
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Phys 1-2-3, 1A-2A-3A — Introductory Physics; Laboratory	4	4	4
Electives (see Index for Liberal Education Category Requirements)	3	3	6
Total credits	15	15	18

Second Year

	Credits — f	w	s
Arch 21 — Architectural Theory and History	3	..	..
Arch 81-82-83 — Architectural Design	6	6	6
ArtH 1 — Principles of Art (C.L.E. Category 4)	..	..	5
ArtS 23A, 24A, 25A — Drawing and Painting I (C.L.E. Category 4)	2	2	2
Biol 1-2 — General Biology	..	5	5
CE 61A (or) MeAg 42 — Surveying	3	..	..
Electives (see Index for Liberal Education Category Requirements)	3	4	..
Total credits	17	17	18

Third Year

	Credits — f	w	s
LA 91-92-93 — Landscape Architectural Design	6	6	6
LA 71-72-73 — Landscape Technology I	4	4	4
LA 115 — Theory of Landscape Form and Structure	..	3	..
LA 62-63 — History and Literature of Landscape Architecture	..	3	3
ArtS 60A-61A-62A — Drawing and Painting II (C.L.E. Category 4)	2	2	2
Hort 21, 22 — Woody Plant Materials I, II	3	..	3
Electives (see Index for Liberal Education Category Requirements)	3	..	..
Total credits	18	18	18

Fourth Year

	Credits — f	w	s
LA 111-112-113 — Landscape Architectural Design	6	6	6
LA 74-75-76 — Landscape Technology II	4	4	4
LA 116 — Theory of Landscape Form and Structure	..	3	..
Arch 133 — Planning	..	..	3
Ecol 50 — Introduction to Ecology	..	3	..
Soil 19 — Introductory Soil Science	4	..	..
Technical electives (see specified departmental list)	3	..	3
Total credits	17	16	16

Fifth Year

	Credits — f	w	s
LA 121-122 — Landscape Architectural Design	6	6	..
LA 124-125 — Landscape Architectural Seminar	2	..	2
LA 123 — Thesis	..	..	12
LA 126 — Professional Relations	..	3	..
Arch 131, 132 — Planning	3	3	..
Technical electives (see specified departmental list)	6	4	3
Total credits	17	16	17

SCHOOL OF CHEMISTRY

Two undergraduate curricula are offered through the School of Chemistry: a 4-year program in chemistry and a 4-year program in chemical engineering. Each program is discussed separately below.

In addition to the curricula mentioned above, a combined chemistry and education curriculum is offered leading at the end of 5 years to the Bachelor's degree in chemistry and the Master's degree in education.

Chemistry

A 4-year curriculum is offered which leads to the degree of bachelor of chemistry, B.Chem.

In addition to the prescribed courses, sufficient approved electives must be taken to complete a total of at least 200 credits.

The curriculum in chemistry fulfills the requirements of the American Chemical Society and also prepares the student for graduate work at any university. Included are courses to provide an adequate background in the related fields of physics and mathematics and to give wide acquaintance with the nontechnical fields. Many students are stimulated to seek graduate degrees in chemistry leading to an even broader selection of careers than is available to the holder of the Bachelor's degree. The chemistry curriculum is often selected by students who plan advanced work in biochemistry. It is also an excellent basis for many other professional careers.

The field of chemistry embraces a multitude of areas of activity from fundamental and applied research to technical sales promotion. Pharmaceutical chemistry, biochemistry, the production of paints, dyes, pigments, synthetic polymers, rubbers, leathers and textiles, fuels, metals, detergents, rocket propellants, and many other fields stem from and depend on chemistry and chemists.

Chemists have in common an interest in the fundamental chemical mechanisms of the world in which we live. Thus the chemist is essentially a research man seeking to understand and control his environment. His choice of field is enormous. He may be interested in the basic biological mechanisms of muscle, or plant photosynthesis or perhaps the development of new rocket fuels or again the chemical events in nuclear disintegrations. He may want to know exactly how molecules are made up from component atoms or he may want to know how to improve antibiotics.

Because chemistry is the basis for so many different types of activity, the holder of a degree in chemistry can choose among many careers. He may become a teacher yet play an active role in advancing our knowledge of science; he may help to control important industrial processes or to develop new processes; he may choose team attack with medical scientists on the crucial problems of disease. Even if he selects a career outside the field of chemistry he may find his chemical knowledge to be of considerable value in solving problems that arise from time to time. His choice is great and his chance for a good position in his chosen area is very good. Today manufacturing chemistry is the largest of all our manufacturing industries.

LOWER DIVISION

First Year

	Credits — f	w	s
GeCh 24, 25 or 24H, 25H — General Principles of Chemistry	5	3	..
AnCh 46, 47A, 47B or 46H, 47H, 48H — Introduction to Analytical Chemistry I, II	..	3	5
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Engl 1-2-3 — Freshman English	3	3	3
Electives	4	3	4
Total credits	17	17	17

Second Year

	Credits — f	w	s
OrCh 61, 62, 63 — Elementary Organic Chemistry	5	5	3
PCh 101 — Physical Chemistry	..	..	4
Math 31-32 — Calculus IV, V	5	5	..
Phys 7-8-9 — General Physics	5	5	5
Electives	3	3	6
Total credits	18	18	18

UPPER DIVISION

Third Year

	Credits — f	w	s
AnCh 111, 112 — Physicochemical Methods of Analysis	3	3	..
InCh 103, 104 — Inorganic Chemistry I, II	..	3	3
InCh 122 — Inorganic Chemistry Laboratory	..	..	2
OrCh 65 — Elementary Organic Chemistry Laboratory	4	..	..
PCh 102, 104, 103 — Physical Chemistry	4	4	4
PCh 105 — Analysis of Data	1	..	..
PCh 106A-B — Physical Chemistry Laboratory (2 cr required)	..	1-2	1-2
Ger 1B-2B-3B — Beginning German (see requirement below)	5	5	5
Total credits	17	16-17	15-16

Fourth Year

Enough credits to meet the graduation requirement of 200 credits and to complete the requirements listed below. However, to count toward graduation, a maximum of no more than 15 credits (including senior thesis) may be taken in any one division of chemistry during the fourth year.

GERMAN LANGUAGE REQUIREMENT

To qualify for a bachelor of chemistry degree a student must demonstrate a reading knowledge of German. Either the completion of Ger 3 or placement in Ger 4 on the German Department placement test is accepted as evidence of a reading knowledge of the language. Credits in German count as nontechnical elective credits, and may be used to meet part of the liberal education requirement.

The Ger 1B-2B-3B sequence is recommended because of its greater emphasis on reading and vocabulary. This may be taken with P-N grading.

High School Language Placement — A student who has had high school foreign language courses cannot register for equivalent beginning courses (1, 2, 3, or 4) on an A-F basis without taking a placement test. Forms are available in 133 Main Engineering. No placement test is required if he registers P-N.

LIBERAL EDUCATION REQUIREMENT AND ELECTIVES

A total of at least 79 elective credits must be taken, including the distributions listed below.

1. Minimum Liberal Education Requirement — In addition to the required courses in the curriculum, 27 credits must be chosen from the categories listed on page 35. A catalog of courses particularly suitable for fulfilling the liberal education requirement will be found on page 36.

2. A minimum of 20 credits from the technical and nontechnical elective courses listed here:

Astronomy	Mathematics	Physiology
Biochemistry	Microbiology	Plant Physiology
Biology	Mineralogy	Zoology
Botany	Physical Geology	Any IT field, except Chemistry
Geology	Physics	
Geophysics	Physiological Chemistry	

3. A minimum of 20 credits in other electives chosen from courses not listed in paragraph 2 above. In certain instances where specialization in an area such as microbiology, biochemistry, or geology is desired, the student may obtain permission by petition to use a smaller minimum of these electives.

COMBINED CHEMISTRY AND EDUCATION CURRICULUM

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

A student may apply for this curriculum during the third quarter of his junior year. He must have at least a C average (2.00) in all courses. In addition, he must complete the speech, health, and psychological examinations and interviews required by the College of Education and secure the approval of his major adviser in chemistry in the Institute of Technology and the Admission Committee of the College of Education.

The student carries courses in both colleges concurrently during the fourth and fifth years and is awarded both degrees when he meets the graduation requirements that include: (1) the liberal education requirement of the Institute of Technology (page 35); (2) the prescribed courses in both colleges and a total of 245 credits; (3) 45 credits of graduate level courses (numbered 100 or higher) in physics and education (maximum of 12 in education) with a B (3.00) average; (4) a research or expository paper; and (5) a minimum of 45 credits earned while in residence in the College of Education. The residence requirement is to be met by transferring to the College of Education for the fifth year of the combined program.

Students are advised to obtain a statement of current requirements for the master of education degree at 206 Burton Hall, the Student Personnel Office. In the third quarter of the third year (junior year) the student should apply for the joint program at the Transfer Window, Office of Admissions and Records, Morrill Hall. At the same time he should apply for student teaching at 227 Burton Hall. During the third quarter of the fourth year the student should apply for transfer to the College of Education at the Transfer Window, Morrill Hall.

First Year

	Credits — f	w	s
GeCh 24, 25 or 24H, 25H — General Principles of Chemistry	5	3	..
AnCh 46, 47A, 47B or 46H, 47H, 48H — Introduction to Analytical Chemistry I, II	..	3	5
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Option I			
Engl 1-2-3 — Freshman English	3	3	3
Physical education (required for the master of education degree)	1	1	1
Electives	3	3	3
Option II			
Engl 1-2-3 — Freshman English	3	3	3
Electives	3	3	3
Total credits (Option I)	17	18	17
Total credits (Option II)	16	17	16

Second Year

	Credits — f	w	s
OrCh 61, 62, 63 — Elementary Organic Chemistry	5	5	3
PCh 101 — Physical Chemistry	..	..	4
Math 31-32 — Calculus IV, V	5	5	..
Phys 7-8-9 — General Physics	5	5	5
Psy 1-2 — General Psychology	3	3	..
Physical education (for those taking Option II; required for the master of education degree)	1	1	1
Electives	..	..	3
Total credits (Option I)	18	18	15
Total credits (Option II)	19	19	16

Third Year

	Credits — f	w	s
InCh 103, 104 — Inorganic Chemistry I, II	..	3	3
OrCh 65 — Elementary Organic Chemistry Laboratory	4	..	..
PCh 102, 104, 103 — Physical Chemistry	4	4	4
PCh 105, 106A-B — Physical Chemistry Laboratory (3 cr required)	1	1-2	1-2
Ger 1B-2B-3B — Beginning German (see requirement above), and electives (those taking Option II may omit 6 of these elective credits)	8	8	8
Total credits	17	16-17	16-17

Fourth Year

	Credits — f	w	s
AnCh 111, 112 — Physicochemical Methods of Analysis	3	3	..
InCh 122 — Inorganic Chemistry Laboratory	..	..	2
Phys 50T, 50A, 51T, 51A — Modern Physics; Statistical Physics	..	5	5
PubH 50 — Personal and Community Health (required for master of education degree)	..	..	3
Ed 55A-B — Introduction to Secondary School Teaching	5	5	..
EdT 68 — Student Teaching in Science	1	1	1
EdT 68A-B-C — Teaching of Secondary School Science	3	1	1
Electives	4	..	4
Total credits	16	15	16

Fifth Year

	Credits — f	w	s
EdCI — Internship	..	..	12
EdT 68 — Student Teaching in Science	..	3	..
EdT 68M — Teaching Secondary School Mathematics	3	..	..
EPsy 208 — Methods in Education Research	..	3	..
HEd 90 — The School and Society	3	..	..
Electives	9	9	3
Total credits	15	15	15

Chemical Engineering

A 4-year curriculum is offered which leads to the degree of bachelor of chemical engineering, B.Chem.E. Students who are interested in pursuing graduate work should consult with their advisers or the department head as early as possible so that the proper program of study can be planned.

In addition to prescribed courses, sufficient electives must be taken to complete a total of 191 credits. Students are urged to consult with their advisers when making out programs of study in order that their best interests may be served.

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

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

In such industries the chemical engineer does basic and applied research, development work, design and modifications of processes and equipment, and plant operation. Some enter sales engineering, marketing, and administration.

The chemical engineer may also enter into the field of nuclear engineering which encompasses processing, separation, development, and testing of materials for nuclear reactors; design and operation of nuclear reactors for research, isotope production, breeding, heat and power generation; and utilization as well as disposal of radionuclides and fission products. He may also enter the field of bioengineering. This involves the application of engineering methods and principles to biological problems ranging from the utilization of the activities of microorganisms to the design of prosthetic devices and artificial human organs.

The curriculum provides opportunities for the student to choose directions of particular interest to him. The curriculum described below is a minimal one and is to serve as a guide. Superior students should plan a more extensive program in consultation with their advisers.

LOWER DIVISION

First Year

	Credits — f	w	s
GeCh 24, 25 — General Principles of Chemistry	5	3	..
Engl 1-2-3 — Freshman English	3	3	3
Math 21A-22A-23A — Analysis I, II, III	5	5	5
AnCh 46, 47A, 47B — Introduction to Analytical Chemistry I, II	..	3	5
Liberal education electives (see Note 1 below)	0-3	3	3
Total credits	13-16	17	16

Second Year

	Credits — f	w	s
Phys 7-8-9 — General Physics	5	5	5
Math 31-32, 33 — Calculus IV, V, VI	5	5	5
OrCh 61, 62 — Elementary Organic Chemistry	5	5	..
Ecol 50 — Introduction to Ecology (see Note 2 below)	..	3	..
Approved biological elective (see Notes 1 and 3 below)	..	..	3
PCh 101 — Physical Chemistry (or) Elective (see Notes 1 and 4 below)	..	..	4-3
Liberal education electives (see Note 1 below)	3	..	..
Total credits	18	18	17-16

UPPER DIVISION

Third Year

	Credits — f	w	s
ChEn 100 — Numerical and Computer Methods in Chemical Engineering	2	..	..
ChEn 101, 102, 103 — Principles of Chemical Engineering	5	5	5
ChEn 119-120 — Chemical Engineering Thermodynamics	..	3	3
PCh 102 or 101, 104 or 102 — Physical Chemistry	4	4	..
Elective (see Notes 1 and 4 below)			
(or) PCh 104 — Physical Chemistry	..	..	3-4
PCh 105 — Analysis of Data	..	1	..
PCh 106A — Physical Chemistry Laboratory	..	..	2
Liberal education electives (see Note 1 below)	3	3	3
Electives (see Note 1 below)	0-3	0-3	..
Total credits	14-17	16-19	16-17

Fourth Year

	Credits — f	w	s
ChEn 104 — Chemical Reactor Analysis	5	..	..
ChEn 111, 112, 113 — Chemical Engineering Laboratory	2	2	2
ChEn 116-117 — Process Evaluation and Design	..	3	3
ChEn 171, 172 — Process Control	..	3	3
MetE 60 — Physical Metallurgy (see Note 5 below)	3	..	..
MetE 161 — Corrosion of Metals (see Note 5 below)	..	2	..
Electives (see Note 1 below)	3-6	3-6	6-9
Liberal education electives (see Note 1 below)	3	3-0	..
Total credits	16-19	16	14-17

Notes:

1. All electives are to be chosen in consultation with the adviser.
2. Transfer students having 6 or more credits of biological science upon admission to the department may petition to replace Ecol 50 with 3 credits of biological science.
3. Approved biological electives include Ecol 51, Biol 1 and 2, GCB 51, or GCB 68. These courses may be taken on a P-N basis.
4. To be chosen from OrCh 63, PCh 103, EE 30, or MM 36. Students planning to take BioC 141-142-148 in the Bioengineering Option should choose OrCh 63.
5. Students who choose Science of Materials (MetE 101-102-103) as electives may take electives in place of MetE 60 and MetE 161.

BIOENGINEERING OPTION

An option is available for students interested in pursuing a career in bioengineering or biomedical science. All or any part of this option may be selected; students should devise a suitable program in consultation with their advisers.

Third Year

Biol 60s — Biochemistry (4 credits)
(or) BioC 141f, 142w, 148s — General Biochemistry; General Biochemistry Laboratory (9 credits)

The liberal education elective in spring quarter should be postponed until the fourth year. Students planning to take BioC 141, 142, 148 should take OrCh 63 in spring quarter of their second year.

Fourth Year

ChEn 181-182-183 — Biological Engineering Analysis (9 credits)

Other courses may be selected from the following list:

MicB 153, 121, 103 — Biology of Microorganisms; Physiology of Bacteria; Ecology of Soil Microorganisms (11 credits)
Phsl 52, 53 and GCB 51 — Principles of Physiology; Cell Biology (9 credits)
BPhy 155, 156, 157 — Biophysics (9 credits)
Other approved biological science electives

Courses selected from the foregoing list may be used in place of 12 elective credits in the fourth year. Students taking more than 12 credits from courses in the list may use these to satisfy the requirements for MetE 60 and 161 and ChEn 171-172.

NUCLEAR ENGINEERING OPTION

For those chemical engineers who may wish to pursue a more active career in the areas of nuclear engineering and science, the course sequence ChEn 161-162-163 — Nuclear Reactor Design, 9 credits, is recommended for the fourth year. The course contents include an introduction to nuclear reactor theory; laboratory studies with a reactor simulator, exponential pile, gamma facility, and a nuclear reactor; identification of current problems in nuclear safety; and opportunities for special study assignments in nuclear engineering.

Chemical Engineering Advisers for Seniors — Professors Amundson, Aris, Ceaglske, Dahler, Fredrickson, Isbin, Ranz, Scriven, Tsuchiya, Davis, Keller, Madden, Carr, Hickman, Schmidt.

SCHOOL OF EARTH SCIENCES

Geology and Geophysics

The Department of Geology and Geophysics is the teaching department of the School of Earth Sciences. It offers a choice of three different 4-year programs in the undergraduate curriculum: Geology Option A and Option B, and Geophysics. A minimum of 200 credits is required for graduation with the degree of bachelor of science in geology, B.S.Geol., for Options A and B, and in geophysics, B.S.Geophys. The classrooms and laboratories of the department are equipped with modern teaching aids and research equipment.

The earth sciences, as integrating sciences, are strongly dependent on a sound foundation in the primary sciences — physics, chemistry, mathematics, and biology. Common to each of the alternative curricula, therefore, is the aim to provide such a foundation in the first 2 years; exposure to other than introductory courses in geology and geophysics is reserved until later. The first year is identical for all three options, students not being required to select an option until the second year. During the second year the three options remain similar enough that a transfer from one to another is still feasible. The main divergence between options comes in the third year.

All curricular options are designed to accommodate two types of students: (a) those preparing for graduate work, and (b) students for whom the B.S. is a terminal degree. The latter will be permitted to include additional geology and geophysics among their electives; the former will be encouraged to elect in other fields of science or nontechnical subjects, reserving advanced earth sciences until Graduate School.

An advanced degree is generally necessary for employment at a fully professional level in research and development work or in teaching in the earth sciences. The bachelor of science degree is suitable preparation for employment on a subprofessional level. Geological scientists are employed by research institutions and government agencies of several types; by business, industrial, or engineering interests engaged in exploration for or exploitation of mineral resources, or needing evaluation of the natural distributions or physical properties of materials in connection with their business; or as teachers.

Language Requirement — Students who have had high school German are encouraged to take the language placement test on entering the University as a means of reducing language credit requirements.

High School Language Placement — A student who has had high school foreign language courses cannot register for equivalent beginning courses (1, 2, 3, or 4) on an A-F basis without taking a placement test. Forms are available in 133 Main Engineering. No placement test is required if he registers P-N.

GEOLOGY — OPTIONS A AND B, GEOPHYSICS

First Year

	Credits — f	w	s
Engl 1-2-3 — Freshman English	3	3	3
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Phys 21, 21A, 22T, 22A — General Physics; Physics Laboratory	..	5	5
Liberal education electives (see Index for Category Requirements)	8	3	3
Total credits	16	16	16

GEOLOGY — OPTION A

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

Second Year

	Credits — f	w	s
Geo 11, 62, 22 — Introductory Physical Geology; Introductory Mineralogy; Introductory Historical Geology	5	5	5
Math 31-32 — Calculus IV, V	..	5	5

Phys 23T, 23A — General Physics; Physics Laboratory	5	..	..
GeCh 14-15 — General Principles of Chemistry	4	4	..
Biol 1 — General Biology	..	..	5
Electives (see statement following 4th year)	3	3	1
Total credits	17	17	16

Third Year

	Credits — f, w, s		
Geo 63, 64, 65, 141 — Introductory Structural Geology; Introductory Sedimentology and Stratigraphy; Introductory Field Geology; Optical Mineralogy and Petrography	3	3	6
Biol 2 — General Biology	5	..	..
Zool 71 — Principles of Invertebrate Zoology (or other Upper Division biology course)	..	..	3
OrCh 61, 62 — Elementary Organic Chemistry	..	5	5
Ger 1-2 — Beginning German (or equiv Russian courses)	5	5	..
Electives (see statement following 4th year)	3	3	..
Total credits	16	16	14

Geo 100 — Field Geology (Summer Session) .... 9 credits

Fourth Year

	Credits — f, w, s		
Geo 99 — Senior Research	..	..	3
Geo 140, 142, 149 — Mineral Systems I, II; Introductory Geochemistry	3	3	3
PCh 107-108 — Elementary Physical Chemistry	3	3	..
Zool 96 — Organic Evolution (or another Upper Division biology course or Geo 105)	0-3	..	0-5
Geology electives (Geo 115 recommended)	3	6	3
Electives (see statement following 4th year)	6	3	3-6
Total credits	15-18	15	15-17

For graduation a total of at least 27 elective credits must be in liberal education courses (see General Curricular Requirements, page 34).

GEOLOGY — OPTION B

In this option the chemical and physicochemical aspects of geology are emphasized, including the structure and composition of minerals, the study of rocks as chemical systems, the distribution and migration of elements, and the deposition of minerals and rocks from solutions and melts. The background science requirement of this option emphasizes chemistry and physical chemistry, with a broad sampling of the other primary sciences.

Second Year

	Credits — f, w, s		
Geo 11, 62, 22 — Introductory Physical Geology; Introductory Mineralogy; Introductory Historical Geology	5	5	5
Math 31-32 — Calculus IV, V	..	5	5
Phys 23T, 23A — General Physics; Physics Laboratory	5	..	..
GeCh 4-5, 6 — General Principles of Chemistry; Principles of Solution Chemistry	5	5	4
Liberal education electives (see statement following 4th year)	3	3	3
Total credits	18	18	17

Third Year

	Credits — f	w	s
Geo 63, 64, 65, 141 — Introductory Structural Geology; Introductory Sedimentology and Stratigraphy; Introductory Field Geology; Optical Mineralogy and Petrography	3	3	6
Biol 1-2 — General Biology	..	5	5
Math 33 — Calculus VI	5	..	..
Phys 50T, 51T — Modern, Statistical Physics (no laboratory)	..	4	4
Ger 1-2 — Beginning German (or equiv Russian courses)	5	5	..
Electives (see statement following 4th year)	3-5	..	..
Total credits	16-18	17	15

Geo 100 — Field Geology (Summer Session) .... 9 credits

Fourth Year

	Credits — f	w	s
Geo 99 — Senior Research	..	..	3
Geo 140,142,149 — Mineral Systems I, II; Introductory Geochemistry	3	3	3
PCh 101, 102, 104 or 103 — Physical Chemistry	4	4	4
Geology electives (Geo 150, 151 or 170A, B, 171 or 115 recommended)	3	3	..
Electives (see statement following 4th year)	4-6	4-6	3-6
Total credits	14-16	14-16	13-16

For graduation a total of at least 27 elective credits must be in liberal education courses (see General Curricular Requirements, page 34).

GEOPHYSICS

Geophysics, which we here restrict to solid-earth geophysics, is the study of the gross structure and physical properties of the earth. Seismology, the most widely recognized branch of solid-earth geophysics, leads to information concerning the major structural features and internal arrangement of the earth. The study of the gravity, magnetic, and electrical properties of the earth is also an important and expanding branch of geophysics. Geophysics is also considered in some definitions to include the physics of the atmosphere, of extraterrestrial bodies, and of interplanetary and interstellar space. Preparation along these lines can be arranged under a combination of disciplines. This option requires intensive training in physics.

Second Year

	Credits — f	w	s
Geo 11, 62, 22 — Introductory Physical Geology; Introductory Mineralogy; Introductory Historical Geology	5	5	5
Phys 23T, 23A, 50T, 51T — General Physics; Physics Laboratory; Modern Physics; Statistical Physics	5	4	4
GeCh 14-15 — General Principles of Chemistry	4	4	..
Math 31-32 — Calculus IV, V	..	5	5
Electives (see statement following 4th year)	3	..	3
Total credits	17	18	17

Third Year

	Credits — f, w, s		
Geo 63, 64, 65 — Introductory Structural Geology; Introductory Sedimentology and Stratigraphy; Introductory Field Geology	3	3	2
Geo 175, 176, 177 — Principles of Geophysical Exploration	2	3	3
Phys 100A-101A-102A — Introduction to Analytic Mechanics	3	3	3
Phys 146, 148 — Vacuum Tube and Transistor Circuits; Applications of Electronic Circuits	4	4	..
Electives (see statement following 4th year)	4	3	6
Total credits	16	16	14

Fourth Year

	Credits — f, w, s		
Phys 103A-104A-105A — Introduction to Electric and Magnetic Fields	3	3	3
Math 147, 148, 149 — Vector Analysis; Differential Equations; Determinants and Matrices	3	3	3
Ger 1-2 — Beginning German	5	5	..
Geo 99 — Senior Research	..	..	3
Electives (see statement following 4th year)	3	3	5
Total credits	14	14	14

Summer Field Course

Geo 100 — Field Geology (to be taken after senior year, or less desirably after junior year) ..... 9 credits

For graduation a total of at least 27 elective credits must be in liberal education courses (see General Curricular Requirements, page 34).

The following substitutions are permitted provided any resulting credit deficit is added to elective requirements:

Phys 100-102-104 for Phys 100A-101A-102A, 103A-104A-105A
EE 74-75, 76 for Phys 103A-104A-105A
EE 30, 30A, 31, 31A, Math 60A for Phys 146, 148
French or Russian for German
Geo 171, 170A, 170B for Geo 175, 176, 177
Math 107A-107B for Math 147, 148, 149

Recommended electives include:

Math 14A, 14B-C, 60A; Phys 149
Stat 90E or 131
Geo 121, 115, 155, 170A, B
EE 107-108

SCHOOL OF MATHEMATICS

Mathematics

A 4-year curriculum is offered which leads to the degree of bachelor of mathematics, B.Math.

In addition to the prescribed courses, a student must meet the nontechnical requirement of 9 credits of Freshman English, the minimum liberal education requirement, and have sufficient approved electives to complete a total of 200 credits for graduation.

This course of study is designed to prepare the student for positions in industry and government research. In addition to a thorough training in mathematics, the student will be provided with fundamental knowledge in physics and chemistry and he may also obtain an introduction to some field of engineering on an elective basis. The curriculum is flexible enough to provide for some specialization such as statistics, mechanics, or numerical analysis. Yet it is broad enough to provide a sound foundation for graduate study leading to a professional career in either pure or applied mathematics and for college and university teaching. A careful selection of electives and options should provide for the individual's special interests.

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

LOWER DIVISION

First Year

See first-year curriculum for the College of Engineering.

Students may substitute an elective for EG 25 by petition. However, students who are not certain whether to major in mathematics or engineering should take EG 25.

If a foreign language is chosen to meet one of the liberal education requirements, it should be either French, German, or Russian.

Second Year

	Credits — f	w	s
Math 31-32, 33 — Calculus IV, V, VI	5	5	5
GeCh 14-15 — General Principles of Chemistry	4	4	..
MM 35 — Statics (or) OrCh 16 — Carbon Compounds (see statement below) (or) Elective	..	..	3-4
Phys 23T — General Physics	4	..	..
Phys 23A, 50A — Physics Laboratory	1	1	..
Phys 50T, 51T — Modern Physics; Statistical Physics	..	4	4
Liberal education electives	3	3	3
Total credits	17	17	15-16

Students who are not certain whether to major in mathematics or engineering or who plan to take MM 36 and 37 in the third year should take MM 35 which is required in engineering.

UPPER DIVISION

Third Year

	Credits — f	w	s
Mathematics option (see below)	3	3	3
Math 107A-B-C — Advanced Calculus (or) Math 130A-B-C — Introduction to Analysis	3	3	3
Phys 100-102-104 — Mechanics, Electricity, and Magnetism (or) MM 36, 37 — Dynamics; Deformable Body Mechanics	4	4	4-0
Technical elective (see statement below)	3	3	3

Liberal education elective	3	3	3-6
Electives	1-2	1-2	1-2
Total credits	17-18	17-18	17

Students planning on graduate study in mathematics should take Math 130A-B-C.

The technical elective can be selected from any IT department. It must be a sequence of 9 credits or more.

Fourth Year

	Credits — f	w	s
Math 142-143 — Matrix Theory with Applications (see statement below)	3	3	..
Math 180 — Group Theory (or) Math 135 — Integral Equations (or) Math 150 — Ordinary Differential Equations (or) Math 169 — Mathematical Theory of Fluid Flow	..	..	3
Math 173-174-175 — Elementary Partial Differential Equations	3	3	3
Mathematics option (see below)	3	3	3
Electives	4	4	4
Liberal education elective	3	3	3
Total credits	16	16	16

Math 131A-B-C may be substituted for Math 142-143, 180. This substitution is recommended for those planning Ph.D. work later.

Any student planning on entering the Graduate School should take a foreign language. A language course can be included as part of the nontechnical requirements or part of the electives.

A minimum of 200 credits is required for the degree bachelor of mathematics.

MATHEMATICS OPTION

One of the following sequences must be completed:

Math 112A-B-C — Mathematical Logic
Math 115A, B-C — Differential Geometry
Math 117A-B-C — Geometry
Math 130A-B-C — Introduction to Analysis
Math 157-158-159 — Methods of Applied Mathematics
Math 161-162-163 — Analytical Dynamics
Math 164, 165, 166 — Theory of Programming Modern Digital Computers
Math 178A-B-C — Introduction to Probability
Math 184, 185-186 — Numerical Analysis
Stat 131-132-133 — Theory of Statistics
Math 181A-B — Introduction to Topology, *and* Math 112 — Set Theory
(or) 1 qtr of Math 117A-B-C — Geometry

COMPUTER SCIENCE OPTION IN MATHEMATICS

Students with interests in computer science may elect the following curriculum in consultation with their adviser.

First Year

	Credits — f, w, s		
Engl 1-2-3 — Freshman English	3	3	3
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Phys 21, 22T — General Physics	..	4	4
Phys 21A, 22A — Physics Laboratory	..	1	1
Math 14A-B — Introduction to Computers, Computer Laboratory	2	..	1
Liberal education elective	3	3	3
Total credits	13	16	17

Second Year

	Credits — f, w, s		
Math 31-32, 33 — Calculus IV, V, VI	5	5	5
GeCh 14-15 — General Principles of Chemistry	4	4	..
Math 14C — Computer Laboratory	..	1	..
Phys 23T, 50T, 51T — General Physics; Modern Physics; Statistical Physics	4	4	4
Phys 23A, 50A — Physics Laboratory	1	1	..
Liberal education electives	3	3	6
Total credits	17	18	15

Third Year

	Credits — f, w, s		
Math 100A-B-C — Mathematics of Symbol Manipulation Systems	3	3	3
Math 107A-B-C — Advanced Calculus	3	3	3
Phys 100-102-104 — Mechanics, Electricity, and Magnetism	4	4	4
Technical elective (see statement below)	..	..	3
Math 164, 165, 166 — Theory of Programming Modern Digital Computers	3	3	3
EE 46, 47 — Circuits; Electronics	4	4	..
Total credits	17	17	16

The technical elective can be selected from any IT department. It must be a sequence of 9 credits or more.

Fourth Year

	Credits — f, w, s		
Math 142-143, 180 — Matrix Theory; Group Theory	3	3	3
Math 173-174-175 — Partial Differential Equations	3	3	3
Math 184, 185-186 — Elementary Numerical Analysis in Engineering; Numerical Analysis in Engineering	3	3	3
Electives	3	3	3
Math 101A-B-C — Nonnumeric and Systems Programming	3	3	3
Liberal education electives	3	3	3
Total credits	18	18	18

COMBINED MATHEMATICS AND EDUCATION CURRICULUM

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

A student may apply for this curriculum during the third quarter of his junior year. He must have at least a C average (2.00) in all courses and a C+ average (2.50) in mathematics. In addition, he must complete the speech, health, and psychological examinations and interviews required by the College of Education and secure the approval of his major adviser in mathematics in the Institute of Technology and the Admission Committee of the College of Education.

The student carries courses in both colleges concurrently during the fourth and fifth years and is awarded both degrees when he meets the following requirements. He must complete the prescribed courses in both colleges and a total of 245 credits. These must include 45 credits of graduate level courses (numbered 100 or higher) in mathematics and education (maximum of 12 in education) with a B (3.00) average. He must also have satisfactory scores on the master of education comprehensive examinations.

Students are advised to obtain a statement of current requirements for the master of education degree at 206 Burton Hall, the Student Personnel Office. In the third quarter of the third year (junior year) the student should apply for the joint program at the Transfer Window, Office of Admissions and Records, Morrill Hall. At the same time he should apply for student teaching at 227 Burton Hall. During the third quarter of the fourth year the student should apply for transfer to the College of Education at the Transfer Window, Morrill Hall.

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

First Year

See first-year curriculum for the College of Engineering.

Second Year

	Credits — f	w	s
Math 31-32, 33 — Calculus IV, V, VI	5	5	5
GeCh 14-15 — General Principles of Chemistry	4	4	..
OrCh 16 — Carbon Compounds	..	..	4
MM 35 — Statics (or) Phys 51T — Statistical Physics (or) Elective (see statement below)	..	..	3-4
Phys 23T — General Physics	4	..	..
Phys 23A, 50A — Physics Laboratory	1	1	..
Phys 50T — Modern Physics	..	4	..
Psy 1-2 — General Psychology	3	3	..
Liberal education elective	..	..	3
Total credits	17	17	15-16

Students who plan to take MM 36, 37 in the third year or who are not certain about majoring in mathematics should take MM 35 which is required in engineering.

Third Year

Mathematics option (see Mathematics Option in Mathematics curriculum)	3	3	3
Math 107A-B-C — Advanced Calculus (or) Math 130A-B-C — Introduction to Analysis	3	3	3
Phys 100-102-104 — Mechanics, Electricity, and Magnetism (or) MM 36, 37 — Dynamics; Deformable Body Mechanics	4	4	4-0

PCh 107-108 — Elementary Physical Chemistry	3	3	..
Physical education	1	1	1
Electives	0-1	0-1	3-6
Liberal education elective	3	3	3
Total credits	17-18	17-18	16-17

Students planning on graduate study in mathematics should take Math 130A-B-C.

Fourth Year

	Credits — f, w, s		
Math 142-143 — Matrix Theory with Applications	3	3	..
Math 180 — Group Theory (or) Math 135 — Integral Equations (or) Math 150 — Ordinary Differential Equations (or) Math 169 — Mathematical Theory of Fluid Flow	..	..	3
Mathematics option (see Mathematics Option in Mathematics curriculum)	3	3	3
Ed 55A-B — Introduction to Secondary School Teaching	5	5	..
EdT 67A-B-C — Teaching Secondary School Mathematics	3	1	1
Ed 67 — Student Teaching in Mathematics	1	1	1
French, German, or Russian	3	3	3
Elective	..	..	6
Total credits	18	16	17

Fifth Year

	Credits — f, w, s		
Math 65 — Introduction to Computer Programming; Math 184 — Elementary Numerical Analysis in Engineering; Math 60 — Synthetic Metric Geometry; Math 66A-B — The Groups of Plane Geometry (six credits required)	4-3	3	..
EdT 67 — Student Teaching in Mathematics (see statement below)	3-0	0-3	..
EdT 68M or A — Teaching Secondary School Science	3	..	..
EPsy 208 — Methods in Educational Research	..	3	..
HEd 90 — The School and Society	..	3	..
PubH 50 — Personal and Community Health	3	..	..
EdCI 199E — Internship	..	..	12
Electives	3-6	6-3	..
Total credits	16-15	15	12

EdT 67 may be taken either fall or winter allowing 3 elective credits in the other quarter.

SCHOOL OF PHYSICS AND ASTRONOMY

Astronomy

Students who wish to prepare for professional work in astronomy and astrophysics should enroll in the curriculum for the IT physics major and request to be assigned an adviser from the Astronomy Department. Information on astronomy and astrophysics options within the physics curriculum may be obtained either from the Astronomy Department office, 357 Physics Building, or the main School of Physics office in 148 Physics Building.

Physics

A 4-year program is offered leading to the degree of bachelor of physics, B.Phys., which requires completion of 200 credits for graduation. A major program in physics is also offered in the College of Liberal Arts (for details, see *College of Liberal Arts Bulletin*). Both programs have similar educational objectives and can provide the student with the fundamental preparation in physics required for graduate school. The curriculum in IT, however, offers greater technical concentration.

A 5-year combined physics-education curriculum offered jointly by the College of Education and the Institute of Technology is described on page 94.

In addition to the prescribed courses totaling 119 credits, 81 credits of electives must be selected from the following four categories:

1. *Physics Electives* — 9 credits chosen from Phys 108, 110, 112, 113, 124, 125, 131, 133A, 134, 135, 136, 149, 165, 166, 167, 171A-B-C, 181A-B-C, Ast 161, 162. The sequence 108-110 or 181A-B-C is strongly recommended for students preparing for graduate school.

2. *Technical Electives*** — From 0 to 42 additional credits in the areas of mathematics, engineering, and the physical sciences (physics, chemistry, astronomy, geology). These electives are to supplement the required physics curriculum and when possible should be from the Upper Division offerings in these areas. EG 25, if taken during the first year, is an acceptable elective in this category.

3. *Liberal Education Electives*** — From 30 to 72 credits (30 credits of which must satisfy the IT minimum liberal education requirement, described on page 35: 6 credits from each of categories 3a and 3b; 9 credits from category 4; and 9 credits from any of the categories except 1d and physics and chemistry courses listed in 2a).

4. *Foreign Language*** — From 0 to 15 credits in one foreign language, depending on the student's previous preparation. French, German, or Russian is recommended; other choices must be discussed with the adviser. For the student with no experience in a foreign language, this corresponds to the completion of a 3-quarter language sequence. Usually, 1 year of language in high school is the equivalent of 1 quarter (5 credits) in college. Courses to substitute for exempted language credits may be taken in either technical or nontechnical areas.

The 119 credits of required courses in the physics curriculum are listed in the sample program below. The sample Upper Division program should not be interpreted as a rigid class schedule; good students are encouraged, for example, to take both the Analytic Mechanics and Electricity and Magnetism sequences in the junior year. Information on various schedule options may be

** May be taken P-N.

obtained from the student's adviser or the program consultant in the School of Physics office.

LOWER DIVISION

First Year

	Credits — f	w	s
Phys 21, 22T — General Physics	..	4	4
Phys 21A, 22A — Physics Laboratory	..	1	1
(Phys 7-8-9, requiring more advanced mathematics prerequisites, substitutes directly for Phys 21, 21A, 22T, 22A, 23T, 23A, and should be elected by appropriately prepared students)			
Engl 1-2-3 — Freshman English	3	3	3
Math 21A-22A-23A — Analysis I, II, III	5	5	5
Electives (language requirement is recommended)	6-8	3-5	3-5
Total credits	14-16	16-18	16-18

Second Year

	Credits — f	w	s
Phys 23T, 50T, 51T — General Physics; Modern Physics; Statistical Physics	4	4	4
Phys 23A, 50A, 51A — Physics Laboratory	1	1	1
GeCh 14-15 — General Principles of Chemistry	4	4	..
Math 31-32, 33 — Calculus IV, V, VI	5	5	5
Electives (Phys 133)	3	3	6-8
Total credits	17	17	16-18

UPPER DIVISION

Third Year

	Credits — f	w	s
Phys 100A-101A-102A — Introduction to Analytic Mechanics	3	3	3
Phys 133 — Physical Optics	..	..	3
Phys 146 — Vacuum Tube and Transistor Circuits	4	..	..
Phys 148 — Application of Electronic Circuits	..	4	..
Mathematics — 9 credits of 100-level mathematics (which may include Math 65)	3	3	3
Electives	6-8	6-8	6-8
Total credits	16-18	16-18	15-17

Fourth Year

	Credits — f	w	s
Phys 103A-104A-105A — Introduction to Electric and Magnetic Fields	3	3	3
Phys 123 — Thermodynamics	3	..	..
Advanced Laboratory (any 2 quarters of the laboratory courses 120-121-122 and 134)	..	3	3
Electives	12	12	11
Total credits	18	18	17

COMBINED PHYSICS AND EDUCATION CURRICULUM

The combined 5-year curriculum between physics and the College of Education leads to the two degrees, bachelor of physics, B.Phys., and master of education, M.Ed. A student may apply for this curriculum during the third quarter of his junior year. He must have at least a C average (2.00) in all courses. In addition, he must complete the speech, health, and psychological examinations and interviews required by the College of Education and secure the approval of his major adviser in physics in the Institute of Technology and the Admission Committee of the College of Education prior to the fourth year.

The student carries courses in both colleges concurrently during the fourth and fifth years and is awarded both degrees when he meets the graduation requirements that include: (1) the prescribed courses in both colleges and a total of 245 credits; (2) 45 credits of graduate-level courses (numbered 100 or higher) in physics and education with a B (3.00) average (9-12 in education, 33-36 in physics or 24-27 in physics and 9 in some academic interest other than physics).

The physics curriculum for the first 3 years is unchanged from that of the IT physics major, but the student must have courses including Psy 1-2 and Public Health (5 or 50) prior to the fourth year. Because of the difficulty in scheduling courses in two departments, however, it is highly advantageous for the student to discuss his program with the physics adviser as early as the sophomore year. Sample curriculum for the combined program is available in the School of Physics office, 148 Physics Building.

In the third quarter of the third year (junior year) the student should apply for the joint program at the Transfer Window, Office of Admissions and Records, Morrill Hall. At the same time he should apply for student teaching in 227 Burton Hall.

During the third quarter of the fourth year the student should apply for transfer to the College of Education at the Transfer Window, Morrill Hall.

COMPUTER, INFORMATION, AND CONTROL SCIENCES

The Department of Computer, Information, and Control Sciences was newly established in 1969. Curricula in computer science in this department (leading to a bachelor of science degree) will be developed in 1969-70. Students interested in a degree in computer science should follow a course of study similar to that described under the Computer Science Option in Mathematics (page 89) or the Computer Science Option in Electrical Engineering (page 52). Freshmen are urged to include Math 14A-B (Introduction to Computers, Computer Laboratory) in their first-year program. Sophomores intending to qualify for a Bachelor's degree in computer science should register for Math 14C (Computer Laboratory). Juniors who intend to qualify for a Bachelor's degree in computer science are urged to construct a program which parallels the third year of the Computer Science Option in Mathematics.

IV. COURSE DESCRIPTIONS

See the *Graduate School Bulletin* for description of courses numbered 200 and above.

Aerospace Engineering and Mechanics

(School of Mechanical and Aerospace Engineering)

Aeronautics (Aero)

5-6. Aerospace Survey and Laboratory. Science, engineering, and aerospace technology. Course areas and technical electives in aero curriculum. Trajectories, orbits, flight mechanics, structures, and materials. Experimental and theoretical aerodynamics. Winged atmospheric, ballistic, and space vehicles. (1 cr per qtr)

100A. Kinematics and Dynamics of Fluid Flow. Kinematics of fluid field including continuity equation, vorticity, circulation, velocity potential, source, and doublet. Application of Gauss's and Stokes's theorem to fluid flow. Flow about cylinder. Potential flow in two and three dimensions. Dynamics, Euler's equation, Bernoulli's equation. Aerostatics. (4 cr, §CE 101A; prereq Math 33 or ¶Math 33; 3 lect and 2 rec hrs per wk)

101A. Incompressible Boundary Layer Theory. Curvilinear coordinate systems, cylindrical and spherical. Viscous incompressible flow. Thin airfoil theory. Stress and strain rate. Navier-Stokes's equation. Boundary layer equation and Blasius solution. Von Karman momentum integral. Pohlhausen method. Turbulent boundary layer. (4 cr, §CE 189; prereq 100A; 3 lect and 2 rec hrs per wk)

102A. Shock Waves and Compressible Fluid Flow. 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. (4 cr; prereq 100A; 3 lect and 2 rec hrs per wk)

104. Incompressible Potential Flow. Irrotational incompressible flow in two dimensions by complex variable methods. Airfoil theory. Three-dimensional potential flow by superposition methods. (3 cr, §CE 188; prereq 100A; 3 lect hrs per wk)

106. Aerodynamics of Lifting Surfaces. Thin airfoil theory, finite wing, aspect ratio, planform and lift distribution, polar diagram of airplanes, dimensional analysis and dynamic similarity. (3 cr; prereq 100A; 3 lect hrs per wk)

107. Performance of Aircraft. Analysis of speed, take off, landing, range, and endurance characteristics of propeller and jet propelled aircraft. Vtol and Stol vehicles. (3 cr; prereq 106; 3 lect hrs per wk)

108. Stability and Control of Aerospace Vehicles. Longitudinal stability and control, power effects, lateral stability and maneuvering flight, introduction to dynamic stability, steady state aeroelasticity, tail and aileron efficiency, wing divergence and aileron reversal, longitudinal stability. Rigid and elastic vehicles. (3 cr; prereq 106; 3 lect hrs per wk)

109. Performance of Missiles and Spacecraft. Missile and spacecraft configurations, equations of motion, burnout velocity of single and multistage missiles, reentry, orbital and escape trajectories. (3 cr; prereq 100A, MM 36; 3 lect hrs per wk)

110. Compressible Viscous Flow. Navier-Stokes's equation of compressible viscous fluid. Energy equation. Boundary layer equations. Karman-Tsien solution. Momentum and energy relations. Turbulent boundary layer. Shock wave and boundary layer interaction. (3 cr; prereq 102A; 3 lect hrs per wk)

111. Dynamic Stability of Aerospace Craft. The general equations of motion for six degrees of freedom. The decoupled specific and generalized equations of motion for longitudinal stability under stick-fixed and stick-free conditions. Routh's discriminant. Solutions of the aerospace craft working equations. Vehicle response to control activation. (3 cr; prereq 106; 3 lect hrs per wk)

115. Aerospace Structures I. Aerospace vehicle load factors and structural design. Deformation analysis of multi-cell torsion box structures. Introduction to fuselage stress analysis; moment distribution, energy methods. (3 cr; prereq MM 37; 3 lect hrs per wk)

116. Aerospace Structures II. Pressurized vehicles. Application of matrix methods to deformation analysis of aerospace structures. Minimum weight design. (3 cr; prereq 115; 3 lect hrs per wk)

121-122-123. Design of Aerospace Elements and Systems. Interdisciplinary projects with students from other departments. (2 cr per qtr; prereq 4th yr engineer and ‡; 4 lab hrs per wk)

130. Design Methods for Aerospace Systems. Organization of engineering design efforts, establishment and application of criteria for judging designs. Parametric, feasibility, and systems studies. (3 cr; prereq 4th yr Aero and ‡; 3 lect hrs per wk)

131. Aerospace Systems Design. Preliminary design synthesis of a selected system. Planning and scheduling. (4 cr; prereq 130 and ‡)

138-139. Summer Engineering Employment. Written report based on summer work in an engineering field (not less than 360 hours per summer). (1-3 cr per qtr; prereq ‡, completion of 3rd yr and ‡ prior to regis)

145-146. Aeromechanics Laboratory I-II. Subsonic and supersonic wind tunnel experiments including lift and drag measurements, flow-visualization methods, pressure-measuring techniques, and boundary-layer measurements. Viscous-flow experiments. Vibrations. Analog methods. Rheological and strength properties of materials and structures. (3 cr per qtr; prereq 100A, MM 37; 4 lab hrs per wk)

147. Aeromechanics Laboratory Projects. Individual experimental projects of a research nature. (3 cr; prereq 146 and ‡; 4 lab hrs per wk)

148. Experimental Supersonics and Hypersonics. Wind tunnel techniques and instrumentation. Flow and model studies. (3 cr; prereq 147)

150. Aeroelasticity I. Static aeroelastic phenomena, closed form and approximate solutions for torsional divergence and aileron reversal. Simple harmonic and arbitrary motion for irrotational incompressible and compressible flow. The gust and flutter problems. (3 cr; prereq 102A and MM 193)

159. Aerodynamic Deceleration I. Aerodynamics of subsonic and supersonic retardation devices. Wake and interference effects. Trajectory calculations, reentry problems and recovery systems. (3 cr; prereq 100A, MM 36)

160. **Aerodynamic Deceleration II.** Review of opening shock theories with emphasis on the mass balance method. Stress analysis, dynamic stability, wake analysis, air resistance of two-body systems, reentry trajectories. (3 cr; prereq 159)

170. **Turbulence and Atmospheric Fluid Dynamics I.** Molecular agitation and turbulence. Introduction to the statistical theory of turbulence. Eulerian and Lagrangian correlations. Spectral distribution of turbulent energy. Karman-Howarth equation. (3 cr; prereq 100A)

171. **Intermediate Inviscid Flow.** Motion and interaction of two-dimensional vortices. Vortex streets and wakes. Vector potentials applied to airfoil theory. Three-dimensional flows induced by the motion of solids. Induced mass and impulsive motion. (3 cr; prereq 104 or Math 174 or CE 188 or ‡)

174. **Entropy Production and Biological Structure.** Review of thermodynamics. Introduction of the Boltzmann-Ehrenfest model. Analysis of the dynamics of the model with application to the development and maintenance of structure in biological systems. (3 cr; prereq ME 30A or equiv)

175. **Random Processes.** Probability densities, averages, correlations, power spectra; interrelations. White noise. Gaussian processes. Random walk problems. Wiener-Hermite functionals for nonlinear processes. Examples for discrete systems and fluid systems. (3 cr; prereq Math 149 or equiv or ‡)

177. **Introduction to Acoustic Propagation.** Derivation of acoustic equations. General properties of propagating fields. Sound problems in the ocean and the atmosphere. (3 cr; prereq Math 147 or ‡)

180. **Introduction to Astrodynamics.** Review of one-body problem, Keplerian orbits. Celestial coordinates, Eulerian angles. Orbit in space, orbital elements. Two-body problem. Methods of orbit determination. Elementary aspects of Earth-Moon trajectories, interplanetary transfer. Impulse and energy requirements. (3 cr; prereq MM 36 or ‡)

183. **One-Dimensional Gas Dynamics.** Properties of normal shocks. Flows through nozzles. One-dimensional channel flow with friction and energy addition. Continuous unsteady one-dimensional flow of perfect fluids. Flow in wind tunnels and diffusers. Shock tube flow. (3 cr; prereq 102A)

184. **Introduction to Hypersonic Flows.** Two-dimensional flow by method of weak waves. Characteristic nets. General hypersonic flow theory. Hypersonic flow past slender bodies with sharp leading edges. Effects of slight leading edge blunting. Two-dimensional supersonic airfoil theory. Resistance and drag. Similarity laws for flows past slender bodies. (3 cr; prereq 102A)

185. **Rarefied Gas Dynamics.** Elements of kinetic theory. Velocity distribution function. Surface interactions. Free molecular flow. Slip flow. Application to low density aerodynamics. (3 cr; prereq 102A or ‡; 3 lect hrs per wk)

190. **Introduction to Magnetohydrodynamics.** Fundamental equations and concepts of magnetohydrodynamics. Transport of magnetic field; magnetohydrodynamic channel flow. Alfven waves. (3 cr; prereq 102A, Math 147 or ‡; 3 lect hrs per wk)

193-194-195.† **Problems in Fluid Mechanics.** Investigation of analytical and experimental problems approved by faculty member. Undergraduate thesis. (0-3 cr; prereq ‡; faculty sponsor required before regis)

For Graduate Students Only

201. Foundations of Fluid Mechanics

202. Finite Waves in Compressible Fluids

203. Linearized Compressible Flow

205. Incompressible Boundary Layer Theory

206. Compressible Boundary Layer Theory

207. Instability of Flow of Viscous Fluids

208. Nonlinear Theories of Hydrodynamic Stability

210-211-212.‡ Selected Topics in Fluid Mechanics

216. Theory of Turbulence

217. Applications of Turbulence Theory

230-231-232. Transonic and Hypersonic Flow

240. Perturbation Methods in Fluid Mechanics

250-251-252. Magneto-Fluid Dynamics

285-286. Selected Topics in Rarefied Gas Dynamics

297-298-299.‡ Seminar: Fluid Mechanics

Mechanics and Materials (MM)

35. Statics. Vector algebra. Application of the equations of equilibrium to the analysis of simple engineering structures and machines. Nature and influence of friction. Elementary theory of statically determinate framed structures. Deformation of structures with axially loaded elements. (4 cr; prereq Math 31 or ¶Math 31, Phys 21)

36. Dynamics. Introduction to vector calculus. Kinematics. Application of principles of particle motion. Conservation principles. Dynamics of particle systems and plane rigid bodies. Technical applications. (4 cr, §Phys 100 or §Phys 100A; prereq Math 32 or ¶Math 32, Phys 21)

37. Deformable Body Mechanics. Introductory treatment of stress and strain at a point. Stress-strain relation in two dimensions. Linear theory of torsion. Bending stresses. Deflection of determinate and indeterminate beams. Instability. (4 cr; prereq 35, Math 31 or ¶Math 31)

92. Statics for Architects. Resolution of force systems. Equilibrium of rigid bodies and analysis of framed structures. Centroids and moments of inertia. (4 cr; prereq Math 22A or equiv; 4 lect hrs per wk; 35 may be substituted for 92)

93. Solid Mechanics for Architects. Introduction to static strength properties of structural materials. Stress and strain. Applications to tension and torsion members, beams, columns, and joints. Design considerations. Material testing. (4 cr; prereq 92; 3 lect and 1 lab hrs per wk; 37 may be substituted for 93)

126. Introduction to the Theory of Elastic Stability. Rational prediction of buckling loads and modes of failure in a variety of structural elements; interpretation of experiments; theoretical basis of design methods. (3 cr; prereq 37)

138. Intermediate Dynamics. Dynamics of rigid-body motions. Extension of the principles of impulse-momentum and work-energy. Euler's equations of motion. The gyroscope. Virtual work. Stability. (3 cr; prereq 36; 3 lect hrs per wk)

142. Experimental Mechanics I. Strain gages. Photoelasticity. Experimental stress analysis. Deformation of beams and columns. Torsion, tensions, and shear tests. (2 cr; prereq 37; 1 lect and 2 lab hrs per wk)

150. Rheology and Strength of Solids. Structure of solids, mechanical models, equation of state. Stress-strain-time and fracture properties under static and dynamic loading. Design significance of creep, relaxation, fatigue, impact, and damping properties. Multi-axial stress and theories of failure. Metallic and nonmetallic structural materials. (3 cr; prereq 37; 3 lect hrs per wk)

151. Fatigue of Materials and Structures. Submicro- and micro-mechanisms of fatigue. Crack initiation and propagation. Statistical aspects. Random loading. Fatigue environment of aerospace structures, its analysis and simulation. Elevated temperature problems. Thermal fatigue. Resonance and acoustic fatigue. (3 cr; prereq 150; 3 lect hrs per wk)

164-165-166.‡ Problems in Mechanics and Materials. Short duration individual research problems, literature studies, and reports. (0-3 cr per qtr; prereq ‡; faculty sponsor required before regis)

176. Introduction to Random Vibration Theory. Statistical descriptions of response of single-degree-of-freedom damped vibrators to nondeterministic forces. Effects of damping and frequency spectra. Measurable quantities. Response of two-degree-of-freedom systems. Impedance methods. Response of linear continuous systems. Comparison higher approximations, descriptions of damping, modal coupling, and spectrum shaping. Acoustic excitation. Fatigue failure criteria. (3 cr; prereq 193)

180. Applied Elasticity I. Kinematics of deformation, strain; invariants; compatibility. Stress; equations of equilibrium; invariants. Stress-strain relations; isotropy; strain energy. Plane strain, generalized plane stress; Airy's stress function; cylinder under pressure. Stress concentration. Thermoelastic equations; sphere; plane problems. (3 cr; prereq 37 or equiv; 3 lect hrs per wk)

181. Applied Elasticity II. Torsion of beams. Warping and stress functions. Multiply-connected cross-sections. Membrane analogy; thin-walled sections. Bending of bars, beams, and rings. Shear center. Beams on elastic foundations. Axial forces. Curved bars, rings. Energy methods for slender bars. Introduction to inelastic behavior, residual stresses, limit analysis. (3 cr; prereq 180 or equiv; 3 lect hrs per wk)

182. Applied Elasticity III. Energy principles of elasticity; potential and complementary energy, reciprocal theorem, variational methods. Approximation techniques: Rayleigh-Ritz, Galerkin Error methods. Applications to torsion and bending. Bending and buckling of thin plates. Lagrange equation. Energy methods for plates. (3 cr; prereq 180 or equiv; 3 lect hrs per wk)

183. Applied Plasticity. Plastic analysis of structures. Load carrying capacity. Limit analysis theorems. Shakedown and plastic collapse. Applications to trusses, beams, and frames. (3 cr; prereq 36, 37)

187. Theory of Linear Viscoelasticity. Linear viscoelastic behavior; linear viscoelastic laws; method of viscoelastic stress analysis; and applications to simple quasi-static viscoelastic problems. (3 cr; prereq 37)

188. Fracture Mechanics. Basic considerations of methods in fracture studies. Theories of strength and mechanical breakdown. Microstructural-dependent as well as time-dependent fracture strength of oriented solids. Analytical investigations of the stress field around a crack and crack propagation. (3 cr; prereq 180 or equiv or ‡)

189. **Applied Thermoelasticity.** Analysis of thermal stresses in various types of structures such as aerospace components, pressure vessels, and nuclear reactors. Inelastic thermal stresses. (3 cr; prereq 180 and ME 133; 3 lect hrs per wk)

193. **Introduction to the Theory of Mechanical Vibrations.** Vibrations of linear lumped-parameter systems. Transient and steady-state behavior of linear systems having a single degree of freedom. Influence of damping. Vibration isolation. Introduction to vibrations of multiple degree of freedom linear discrete systems. (3 cr; prereq 36)

For Graduate Students Only

201. Advanced Dynamics

202. Gyroscopic Systems

206. Numerical Methods in Mechanics

207. Advanced Numerical Methods in Mechanics

210. Theory of Vibrations I

211. Theory of Vibrations II

212. Theory of Vibrations III

213. Advanced Topics in the Theory of Nonlinear Vibrating Systems

222. Theory of Perfectly Plastic Solids

223. Advanced Topics in Plasticity

227. Theory of Elastic Stability

235-236-237. Theory of Mechanical Behavior of Solids with Application

241-242. Theory of Viscoelasticity

264-265-266.‡ Selected Topics on Mechanics and Materials

285. Continuum Mechanics

290. Theory of Plates and Shells

291. Advanced Theory of Shells I

292. Advanced Theory of Shells II

294. Theory of Elasticity I

295-296. Theory of Elasticity II and III

297-298-299.‡ Seminar: Mechanics and Materials

Agricultural Engineering (AgEn)

(College of Agriculture, Forestry, and Home Economics)

10. **Water Supply, Sanitation, and World Food Production.** Development and utilization of available water resources for food production in developing countries,

including construction of sanitary water wells, pumping methods, irrigation requirements and methods, drainage control, water quality and waste disposal. (3 cr; intended primarily for nonengineers; prereq soph or △; 2 lect hrs and 3 lab hrs per wk)

20. **Introductory Agricultural Engineering.** Interrelation of basic biological and environmental engineering and management requirements for food production. Examples in several fields of agricultural engineering are portrayed through digital and analog models. (3 cr; 2 lect and 3 lab hrs per wk) Jordan, Flikke

90. **Soils Engineering.** Mechanical and hydraulic properties of soils, moisture constants, pressure and bearing characteristics for structural and mechanical design. (3 cr; prereq MM37; 2 lect and 3 lab hrs per wk) Flikke

91. **Design and Management of Agricultural Machinery.** Principles of operation and performance characteristics of agricultural machinery. Design of machine elements and assemblies. Management of machinery. (3 cr; prereq ME 22; 2 lect and 3 lab hrs per wk) Smith

94. **Elementary Hydrology, Erosion Control.** Precipitation, infiltration, and runoff. Estimating peak runoff. Mechanics of soil erosion. Estimating soil losses. Design of graded and storage-type terraces, grass waterways, and diversions. Introduction to erosion control structures. (3 cr; prereq 90 or ‡, CE 101A; 3 lect hrs per wk) Larson

97. **Agricultural Structures Design.** Layout of production facilities. Functional requirements for livestock and crop production structures and equipment. Selection of materials and construction methods. (3 cr; prereq 90, MM 37; 2 lect and 3 lab hrs per wk) Jordan, Pomroy

100. **Employment Evaluation.** Required of students in the work-study program during the employment periods. Optional for students with summer employment. (1 cr per qtr) Boyd

121. **Agricultural Tractors.** Tractor engines, cycle analysis, combustion, and fuels. Chassis mechanics, transmission and final drives, hydraulic systems, hitches. Tractor performance. (3 cr; prereq ME 31A; 2 lect and 3 lab hrs per wk) Strait

124. **Drainage and Irrigation Engineering.** Soil-water-plant relationships. Flow of water into and through agricultural soils. Conveyance of irrigation and drainage waters. Water quality, supply, and legal and economic aspects of soil moisture control. (3 cr; prereq 90, 94 or ‡; 3 lect hrs per wk) Allred, Gilley

127. **Agricultural Process Engineering.** Properties of air-water vapor mixtures. Engineering principles of moisture migration and heat transfer applied to drying of grain crops. Fan characteristics and selection. Refrigeration theory and applications. Size reduction, cleaning and sorting of agricultural products. (3 cr; prereq ME 31A, ME 133; 2 lect and 3 lab hrs per wk) Hustrulid

141. **Design of Agricultural Machinery.** An engineering design project involving a farm machine or component assembly and covering the whole range of the design process from concept through analysis and layout to the preparation of a final report. (3 cr; prereq 91; 1 lect and 6 lab hrs per wk) Strait

144. **Advanced Drainage and Irrigation.** Evapotranspiration requirements; pump design and selection for drainage and irrigation; water quality; hydraulic design and construction of irrigation and drainage systems. (3 cr; prereq 124; 3 lect hrs per wk) Allred, Gilley

147. Agricultural Structures and Animal Environment. Engineering principles combined with biological principles to develop a design procedure for nonfield agricultural systems in which the maximum profit can be obtained. The homeothermic mechanisms of animals used to indicate the influence of thermal environment upon animal growth and production. Techniques of labor efficiency and automation used in design. Technology of building designs. Material selection and structural design for economic buildings. (3 cr; prereq 97, ME 133; 3 lect hrs per wk) Jordan

160. Agricultural Engineering Instrumentation. Application of basic electrical instruments to measurement and control of temperature, relative humidity, air flow, and radiation. Dynamic responses of instruments and control circuits. Physical measurements relating to soils and crops. Statistics of random errors. (3 cr; prereq EE 46, Math 32, Phys 50; 2 lect and 3 lab hrs per wk) Hustrulid

161. Agricultural Machine Analysis. Advanced design problems. Application of principles of dynamics to the design of agricultural machinery. Experimental measurement of working forces and stress. Motion analysis. (3 cr; prereq 141; 1 lect and 6 lab hrs per wk) Smith

164. Advanced Soil and Water Engineering. Hydraulic design of erosion control structures; drop spillways, chutes, conduit spillways, combination with grass spillways. Benefits versus costs. Field surveys and layouts for irrigation, drainage, and erosion control. Runoff measurements. (4 cr; prereq 124, CE 61A; 2 lect and 6 lab hrs per wk) Gilley, Larson

165. Watershed Engineering. Flood control methods for small watersheds. Location and design of detention reservoirs, channel improvements. Evaluation of benefits and costs. Water storage, multi-purpose planning. Flood forecasting, zoning. Land treatment effects. Sediment yield and control. (3 cr; prereq 94 or ‡, CE 161; 2 lect hrs per wk, 1 hr rec) Larson

167. Advanced Agricultural Structures. Study of the functional requirements of farm structures with respect to man, animals, and crops, and the development of means of providing structures to fulfill the functional requirements. Application of the science and art of engineering in the solution of environmental problems. Advanced planning in the integration of structural environmental design. (3 cr; prereq 97, ME 133, ME 160A; 3 lect hrs per wk) Jordan

180. Radioisotope Measurements. Properties of nuclear radiation. Geiger-Müller, proportional, and scintillation detectors. Gamma ray spectrometry. Statistics of nuclear radiation measurement. Applications of radioisotope measurement in agricultural engineering. (3 cr; Phys 50T, Math 32; 2 lect and 3 lab hrs per wk) Hustrulid

181. Problems in Agricultural Engineering: Power and Machinery. (2-4 cr per qtr; prereq sr status and ‡) Strait, Smith, Schertz

184. Problems in Agricultural Engineering: Soil and Water. (2-4 cr per qtr; prereq sr status and ‡) Allred, Larson, Manson

187. Problems in Agricultural Engineering: Structures and Processing. (2-4 cr; prereq sr status and ‡) Jordan, Hustrulid, Flikke, Pomroy

For Graduate Students Only

200. Seminar

211-212-213. Advanced Problems and Research

230. Agricultural Engineering Similitude

254. Hydrologic Modeling: Small Watersheds

257. Moisture and Heat Transfer

School of Architecture and Landscape Architecture

Architecture (Arch)

21. Architectural Theory and History. An introduction to architecture, the philosophy and principles of architecture as an art, a survey of architectural history with emphasis upon the development of contemporary architecture from its roots in the 19th century until the present time. (3 cr; 3 lect hrs per wk)

51. Ancient Architecture. The history of architecture in ancient Mesopotamia, Egypt, Crete, Greece, and Rome through the Augustan Age. (3 cr; prereq 21; 3 lect hrs per wk)

52. Late Roman and Medieval Architecture. The history of architecture from the time of Augustus through the Romanesque period. (3 cr; prereq 21; 3 lect hrs per wk)

53. Gothic and Early Renaissance Architecture. The history of architecture from the late 12th century through the 14th century. (3 cr; prereq 21; 3 lect hrs per wk)

54. Renaissance and Baroque Architecture. The history of architecture from the time of Brunelleschi until the French Revolution. (3 cr; prereq 21; 3 lect hrs per wk)

55. American Architecture and the 19th Century. The history of pre-Columbian and colonial architecture in America and European architecture through the early 19th century. Research paper. (3 cr; prereq 21; 3 lect hrs per wk)

56. Modern Architecture. The history of architecture in America and Europe from the late 19th century until the present time. Field trip. (3 cr; prereq 21; 3 lect hrs per wk)

71-72-73. Building Technology. Principles, techniques, materials, and equipment involved in building. (4 cr per qtr; prereq 2nd yr; 4 lect hrs per wk)

74-75-76. Building Technology. Principles, techniques, materials, and equipment involved in building. (4 cr per qtr; prereq 73; 4 lect hrs per wk)

81-82-83. Architectural Design. Basic exercises in composition of line, form, proportion, color, and texture. Elements of architectural design. Architectural drawing. Model making. (18 cr [normally 6 cr per qtr]; prereq 2nd yr for IT students, jr for CLA students and △; 18 lab hrs per wk; entrance fall qtr only)

91-92-93. Architectural Design. Architectural problems with emphasis on development of structures as an integral part of design; site planning. (18 cr [normally 6 cr per qtr]; prereq 83; 18 lab hrs per wk)

101-102-103. Tutorial Work in History of Architecture. Reading and written reports on special historical problems. (2 cr per qtr; prereq 56 or ‡; 1 conf and 5 research hrs per wk)

104. Seminar: European Architecture. Contemporary architecture from the beginning of the modern movement until the present time. (3 cr; prereq 56 or ‡; 3 seminar hrs per wk)

105. Seminar: Scandinavian Architecture. Survey of Scandinavian architectural history with emphasis upon the development of modern architecture in Denmark, Finland, Norway, and Sweden. (3 cr; prereq 56 or ‡; 3 seminar hrs per wk)

106. Seminar: American Architecture. Contemporary architecture in the United States from the period of Henry Hobson Richardson until the present time. Field trip. (3 cr; prereq 56 or ‡; 3 seminar hrs per wk)

111-112-113.† Architectural Design.** Advanced architectural problems of complex requirements, involving thorough study and detailed solution; electrical and mechanical equipment as well as structure as an integral part of design; research techniques. Individual effort and group collaboration. (21 cr [normally 7 cr per qtr]; prereq 93 and MM 93; 21 lab hrs per wk)

115-116. Structure and Form in Architecture. Structural materials and systems, and their application, with particular emphasis on logical structure as a form generator. (3 cr per qtr; prereq MM 92; 2 lect and 3 lab hrs per wk)

117. Structure and Form in Architecture. Structural materials and systems, and their application, with particular emphasis on logical structure as a form generator. (3 cr; prereq MM 92, Arch 115 or 116, and ‡; 2 lect and 3 lab hrs per wk) Michelson

121-122.† Architectural Design.** Building design and development in the urban context. Individual and collaborative effort; survey and analysis of urban problems, reporting and preparation of large-scale proposals. (18 cr [normally 9 cr per qtr]; prereq 113 and CE 41; 27 lab hrs per wk)

123. Architectural Thesis.** Individual choice, study, and solution of an architectural problem to demonstrate proficiency in all phases of design. (12 cr; prereq 122 and submission of a definitive thesis program during qtr prior to thesis; 36 lab hrs per wk)

126. Professional Relations. Relations of the architect to clients, contractors, and fellow practitioners; procedures of architectural practice. (3 cr; prereq 4th yr; two 2-hr seminars per wk)

131. Planning. History and theory of planning. (3 cr; 3 lect hrs per wk)

132. Planning. Conceptualization of the role of individual disciplines in the planning process: architecture, economics, engineering, geography, public administration, public health, and sociology. (3 cr; 3 lect hrs per wk)

133.* Planning. Community facilities and housing. (3 cr)

134.* Planning. Tutorial work in community facilities and housing. (3 cr; prereq 133 or ‡)

150. Institutional Planning. (2 cr; prereq 113 and ‡)

151-152-153. Theory of Architecture. (2 cr per qtr; prereq ‡)

** Two summers, or 800 hours, of practical experience are prerequisite for enrollment in Arch 123.

170.* **Cityscape.** The city and its components as aesthetic elements. (3 cr; prereq 93)

171-172. Urban Form. Principles and techniques involved in city design. (3 cr per qtr; prereq 113 and 133)

For Graduate Students Only

201-202-203.* **Special Research in Architectural History**

231-232-233.* **Planning**

251-252-253.* **Architectural Design**

261-262-263.* **Selected Problems in Architecture**

271-272-273.* **Problems in City and Community Design**

274-275-276. Seminar: Design Evaluation

For related courses required of architectural students (listed under architectural curricula) see respective department announcements for detailed information.

Landscape Architecture (LA)

21. Introduction to Landscape Architecture. Analysis of the design potential of materials of the landscape; exercises in critical assessment of land developments and detail landscapes; exploration of the role of the landscape architect in shaping the natural and cultural environment; brief historical review of site developments. (3 cr; 3 lect hrs per wk)

62-63. History and Literature of Landscape Architecture. A search for design principles as expressed in landscapes created by man from ancient times to the contemporary period. Specific focus on analysis of the visual form of environments as outgrowths of geographical, cultural, and technological determinants. (3 cr per qtr; 3 lect hrs per wk)

71-72-73. Landscape Technology I. Lectures, exercises and projects in: ground form manipulation, earthwork, computation, and drainage techniques; layout of circulation and landscape utilities systems; land analysis procedures and techniques. (4 cr per qtr; prereq CE 61A or MeAg 42; 2 lect hrs per wk and 6 lab hrs per wk)

74-75-76. Landscape Technology II. Lectures, exercises, and projects in: horticultural considerations in site development; landscape construction materials and construction techniques; working document preparation and site supervision procedures. (4 cr per qtr; Hort 74 and 75 may be substituted for LA 74 and 75; 2 lect hrs and 6 lab hrs per wk)

91-92-93. Landscape Architectural Design. Lectures and projects in: exploration of the design potential of natural land materials; exploration of landscape survey and analysis techniques; assessment of the elements of environment as they condition design potential. Exploration of methodologies for solving design problems; exploration of methods of expressing landscape form both graphically and through models; design of small scale site systems with simple variables. (6 cr per qtr; prereq Arch 83 or ‡; 2 lect and 12 lab hrs per wk; Hort 93 may be substituted for LA 93)

96. Special Problems in Landscape Architectural History. (1-6 cr; prereq ‡)

97. Special Problems in Landscape Architectural Theory. (1-6 cr; prereq ‡)

98. Special Problems in Landscape Architectural Design. (1-6 cr; prereq ‡)

99. Special Problems in Landcsape Architectural Technology. (1-6 cr; prereq ‡)

101. Communicating Landscape Quality. Lectures and exercises in drawing techniques focused on developing graphic skills for designers working predominantly with exterior environments. (3 cr per qtr; prereq 93 or ‡; 1 lect and 6 lab hrs per wk)

111-112-113. Landscape Architectural Design. Lectures and projects continuing the areas of concern developed in the initial design course series; assessment of existing man-ordered siting systems; design of large scale site systems with complex variables. (6 cr per qtr; prereq 93 or ‡; 2 lect and 12 lab hrs per wk; Hort 112 may be substituted for LA 112)

115-116. Theory of Landscape Form and Structure. Studies in landscape perception; lectures, discussions, and exercises in: application of abstract design principles to the assessment of land developments; review of psychological and social implications of land developments; exploration of the design potential of landscape materials; investigation of contemporary problems in land development including all scales and types of land uses. (3 cr per qtr; prereq 91 or ‡; 3 lect hrs per wk)

121-122. Landscape Architectural Design. Research, analysis, and design of large-scale land development problems. Urban design and regional design collaboratives with fellow design professions and technical disciplines. (6 cr per qtr; prereq 113; 1 lect hr and 15 lab hrs per wk)

123. Thesis. Definition of a landscape problem; research and analysis of design potentials; projection of a solution to the problem to demonstrate proficiency in all phases of landscape architecture. Problem area to be selected in consultation with instructor. A definitive program for design must be submitted before registration. (12 cr; prereq terminal qtr; 36 lab hrs per wk)

124-125. Landscape Architectural Seminar. Analysis of design principles and design goals in the modern profession. Assessment of the role of the landscape architect in modern society. Review of current site development projects. Investigation in depth into specific areas of land development. (2 cr per qtr; prereq terminal yr of study)

126. Professional Relations. Professional ethics, responsibility, and relations in business. Office management, preparation of professional communications, estimates, specifications, and contracts. Lectures, written exercises, and office visits. (3 cr; prereq terminal yr of study)

131-132-133.† Selected Problems in Landscape Architecture. (Cr ar; prereq ‡)

Art, Studio (ArtS)

(College of Liberal Arts)

23A, 24A, 25A. Drawing and Painting I. (2 cr per qtr; for architects only)

60A-61A-62A. Drawing and Painting II. (2 cr per qtr; for architects only; prereq 25A)

Art History (ArtH)

1. **Principles of Art.** Lecture and laboratory: basic problems of art. Examples from painting, sculpture, and architecture of various periods illustrate general cultural factors that influence production of art and basic problems of design and of technique. Laboratory-discussion sessions introduce student to practical problems arising from nature of materials of visual arts. (5 cr, $50; prereq fr and soph only; 2 lab hrs) Art History staff

Biology (Biol)

(College of Biological Sciences)

1-2.† **General Biology.** A study of plants, animals, and microbes. Includes an introduction to ecology, physiology, classification, cytology, energetics, genetics, development, and evolution. A tutorial room is available for students requiring special assistance. Lectures will be conducted over closed circuit TV. Must be taken in sequence. (5 cr per qtr; no prereq for 1, 1 for 2... high school chemistry recommended)

Chemical Engineering (ChEn)

100. **Numerical and Computer Methods in Chemical Engineering.** Computer programming with applications to chemical and engineering problems. This course is a prerequisite to all other courses in the department. (2 cr; 2 lect and 1 rec hrs per wk) Ceaglske

101. **Principles of Chemical Engineering.** Energy and material balances. Equilibrium stage operations applied to chemical engineering unit operations. (5 cr; prereq 3rd yr and ¶100, ¶PCh 101; 3 lect and 3 rec hrs per wk) Staff

102. **Principles of Chemical Engineering.** Fluid dynamics and its application to chemical engineering unit operations. (5 cr; prereq 101; 3 lect and 3 rec hrs per wk) Scriven

103. **Principles of Chemical Engineering.** Heat and mass transfer and its application to chemical engineering unit operations. (5 cr; prereq 102; 3 lect and 3 rec hrs per wk) Ranz

104. **Chemical Reactor Analysis.** Chemical kinetics. Principles of reactor design for homogeneous and heterogeneous reactions. Analysis of the reactor from a kinetic and thermodynamic point of view. (5 cr; prereq 103, 120, PCh 104; 3 lect and 3 rec hrs per wk)

111. **Chemical Engineering Laboratory.** Applications of unit operations; principles of fluid flow, heat and mass transfer experiments, with reports. (2 cr; prereq 103; 4 lab hrs and 1 lab conf hr per wk)

112. **Chemical Engineering Laboratory.** (See ChEn 111) (2 cr; prereq 111; 4 lab hrs and 1 lab conf hr per wk)

113. **Chemical Engineering Laboratory.** (See ChEn 111) (2 cr; prereq 112; 4 lab hrs and 1 lab conf hr per wk)

116-117. **Process Evaluation and Design.** Dynamics of chemical engineering industries, economics of process evaluation, bases for cost estimations, and expansion of activities considered. Plant designs prepared and compared with actual installations. Special applications of unit operations, reaction kinetics, and thermodynamics. (3 cr per qtr; prereq 103; 3 lect hrs per wk for 116, 4 lect and lab hrs per wk for 117)

119-120. Chemical Engineering Thermodynamics. The principles of thermodynamics applied to batch and particularly to flow systems. Generalized law of corresponding states and fugacity applied in practical problems of physical and chemical equilibrium. (3 cr per qtr; prereq 100 and PCh 101; 2 lect and 2 rec hrs per wk)

152. Chemical Process Laboratory. Applications of principles covered in ChEn 104 in pilot or semiplant laboratory. (2 cr; prereq 101, 104)

153-154-155-156.‡ Special Problems. Investigations in chemical engineering. Library or laboratory research. (Cr ar; 1 conf hr per wk, lab hrs ar) Staff

161-162-163. Nuclear Reactor Design. An engineering approach to the development and application of nuclear reactor theory, including basic nuclear chemistry and physics, mathematical developments and special techniques, design, operation, and control of homogeneous and heterogeneous reactors, and nuclear reactor economics. Laboratory credit available. (3 cr per qtr; prereq ♯; 3 lect hrs per wk) Isbin

171-172. Process Control. Theory and application of instrumentation and control with particular emphasis on application to the chemical industry, including analytical methods. (3 cr per qtr; prereq 4th yr or ♯; 3 lect and rec hrs per wk for 171, 2 lect and 3 lab hrs per wk for 172) Ceaglske

173. Advanced Process Control. (Continuation of 171-172) Additional methods such as the root-locus and Guillemin's method for the analysis and design of process control systems are covered. (3 cr; prereq 172; 3 lect and rec hrs per wk) Ceaglske

181-182-183. Biological Engineering Analysis. Modeling and analysis of biosystems. Thermodynamics, transport and transfer, biochemical reactions, growth and death processes are discussed from both deterministic and probabilistic viewpoints. (3 cr per qtr; prereq ♯) Tsuchiya, Keller, Fredrickson

For Graduate Students Only

201-202-203.‡ Seminar

205-206-207.‡ Physical Rate Processes and the Transfer Operations

208. Intermediate Fluid Mechanics

209-210. Physical Rate Processes

211-212-213. Molecular Theory of Transport Processes

214-215-216. Advanced Mathematics for Chemical Engineers

217. Analysis of Chemical Engineering Problems

218. Advanced Topics in Chemical Engineering

219-220. Advanced Chemical Engineering Thermodynamics

221-222-223. Chemical Reaction Kinetics

224. Problems in Fluid Mechanics

225. Tensors and Field Theory with Applications to Continuum Mechanics

226. Boundary and Interface Mechanics

227. Principles and Applications of Rheology

228. Advanced Topics in Fluid Mechanics and Transport Processes

230. Intermediate Chemical Reactor Analysis

231-232-233. Chemical Rate Processes and Reactor Design Principles

264. General Survey of Chemical Engineering

301-302-303. Research in Chemical Engineering

Chemistry

Analytical Chemistry (AnCh)

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

40. Introduction to Analytical Chemistry. Equilibria involved in analytical processes. Properties and formation of precipitates. Methods of separation. Introduction to electrochemical methods. (4 cr; for physics majors; prereq GeCh 14, 15; 3 lect and 4 lab hrs per wk)

46. Introduction to Analytical Chemistry I. Lecture. Equilibria involved in analytical processes. Properties and formation of precipitates. Methods of separation. Introduction to electrochemical methods. (3 cr; prereq GeCh 5 or 25 or ¶GeCh 5 or ¶25)

46H. Honors Course: Introduction to Analytical Chemistry I. (3 cr; prereq GeCh 5 or 25 or ¶GeCh 5 or ¶25, and ‡)

47A. Introduction to Analytical Chemistry II. Lecture and laboratory. Theoretical fundamentals of volumetric processes in general, including an introduction to physical methods of endpoint detection. (3 cr; prereq 46)

47B. Introduction to Analytical Chemistry II. Laboratory. (2 cr; prereq 47A or ¶47A)

47H. Honors Course: Introduction to Analytical Chemistry II. Lecture. (3 cr; prereq 46 and ‡)

48H. Honors Course: Introduction to Analytical Chemistry II. Laboratory. (2 cr; prereq 47H or ¶47H and ‡)

57A. Quantitative Analysis. A survey of modern quantitative methods of analysis. Lecture. (3 cr [57A, 57B†]; for nonchemistry majors; prereq GeCh 5)

57B. Quantitative Analysis. A survey of modern quantitative methods of analysis including elementary physicochemical procedures. Laboratory. (2 cr; for nonchemistry majors; prereq 57A or ¶57A)

96-97-98.‡ Senior Thesis. A written final senior thesis report is required. (Cr ar; prereq 4th yr and ‡) Staff

103. Qualitative Inorganic Microanalysis. Use of microscope. Technique of handling small amounts of materials. Inorganic qualitative analysis by means of crystal reactions and modern spot reactions. (3 cr; prereq 47 or 47B) Sandell

104. Polarizing Microscope. Its use and application to chemistry. Identification of substances. (3 cr; limited to 16 students; prereq 47 or 47B and Phys 3, 6 or 9, or ‡) Sandell

105. Quantitative Inorganic Microanalysis. Representative methods of micro- and semimicroanalysis; gravimetric, volumetric, and colorimetric. (3 cr; limited to 16 students; prereq 47 or 47B) Sandell

106-107-108.‡ General Technical Analysis. Analysis of commercially important materials such as steel, nonferrous alloys, ores, and glass; use of microscope in technical problems, quantitative analysis of heterogenous mixtures, particle size determinations. (2 or 3 cr per qtr; prereq 47 or 47B) Sandell

111. Physicochemical Methods of Analysis. Lecture. Optical and electrochemical methods and methods of separation. (3 cr; prereq 47 or 47B, PCh 101)

112. Physicochemical Methods of Analysis. Laboratory course. Quantitative application of electrochemical, optical and other physical techniques. (3 cr; prereq 111)

115. Advanced Analytical Chemistry. Equilibria in aqueous and nonaqueous systems. (3 cr; prereq 47 or 47B or equiv and PCh 101)

117. Electrochemical Methods of Analysis. Lecture. Potentiometric, coulometric, polarographic, and other electrical methods. (4 cr; prereq 111 or 211)

118. Electrochemical Methods of Analysis. Laboratory course. (3 cr; prereq 117)

140. Water Analysis. Analysis of potable water with interpretation of results. (2 cr; prereq 47 or 47B) Sandell

141-142-143.*‡ Seminar: Modern Problems in Analytical Chemistry. (1 cr per qtr; prereq 111)

For Graduate Students Only

201-202-203.‡. Selected Topics in Analytical Chemistry

211. Physicochemical Methods of Analysis (Lecture)

212. Physicochemical Methods of Analysis. (Laboratory)

223.* Analysis of Complex Materials

227.* Optical Methods of Analysis (Lecture)

235-236-237.‡ Research Seminar: Analytical Chemistry

262. General Survey of Analytical Chemistry

301-302-303.‡ Research in Quantitative Analysis

General Chemistry (GeCh)

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

4-5. General Principles of Chemistry. An introduction to chemistry from the standpoint of atomic structure, periodic properties of elements and compounds derivable from structural considerations; a study of the laws governing behavior of matter, theories of solutions, acids, bases, and equilibrium. (5 cr per qtr, §14-15, §24, 25; prereq predicted math GPA 1.90 on ACT; Math Z or college course in algebra . . . 4 yrs high school math and high school chemistry recommended; 4 lect, 1 rec, and 3 lab hrs per wk) Staff

6. Principles of Solution Chemistry. Lecture and laboratory work related to the chemistry of selected cations and anions. The detection and behavior of these ions are included as well as heterogeneous and homogeneous equilibrium systems. Attention is given to oxidation-reduction systematics, complex ion formation as it relates to aqueous solution chemistry and general chemical phenomena interrelated with structure. (4 cr; prereq 5 or 15 or 25; 3 lect and 4 lab hrs per wk) Staff

14-15. General Principles of Chemistry. Fundamental principles of chemistry. (4 cr per qtr, §4-5, §24, 25; prereq Phys 21, 22 or 22T or ‡; 3 lect and 4 lab hrs per wk) Staff

24. General Principles of Chemistry. Selected topics in chemistry: atomic structure, molecular structure, chemical stoichiometry, kinetic theory. Course designed for the major in chemistry or closely allied fields. (5 cr, §4, §14; prereq 4 yrs high school math, 1 yr high school chemistry and 1 yr high school physics recommended; 3 lect plus two 3-hr labs per wk) Staff

24H. Honors Course: General Principles of Chemistry. (5 cr, §4, §24; prereq ‡) Staff

25. General Principles of Chemistry. Selected topics in chemistry: gas phase chemical equilibrium, chemical kinetics, electrochemistry. (3 cr, §4-5, §14-15; prereq 24; 2 lect plus one 3-hr lab per wk) Staff

25H. Honors Course: General Principles of Chemistry. (3 cr, §4-5, §14-15; prereq 24 or 24H and ‡) Staff

Inorganic Chemistry (InCh)

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

96-97-98.‡ Senior Thesis. Written quarterly reports are required. The final quarter's report must be the complete senior thesis. (Cr ar; prereq 4th yr and △) Staff

103. Inorganic Chemistry I. Atomic structure, structure and bonding in covalent molecules and ionic crystals, thermochemistry of chemical bonding. Applications to chemistry of nontransition elements. (3 cr; prereq PCh 101 and 102) Henneike

104. Inorganic Chemistry II. Chemistry of transition metal and rare earth compounds; nomenclature and stereochemistry; thermodynamics and kinetics of complex ion reactions, crystal field, ligand field, molecular orbital, and valence-bond descriptions of bonding; solution chemistry of transition elements. (3 cr; prereq 103) Henneike, Reynolds

122. Inorganic Chemistry Laboratory. Synthesis and physical measurements of selected compounds. Equilibria and kinetics of selected reaction systems. (2 cr; prereq 103 and ¶104) Britton, Henneike

123-124.‡ Advanced Inorganic Chemistry Laboratory. Advanced laboratory work in physical and synthetic methods. The specific experiments to be done will be determined by the student in consultation with the instructor. Detailed instructions for a wide variety of experiments will be available. (2 cr per qtr; prereq 122, ‡) Brasted, Britton, Conroy

140-141-142.‡ Selected Topics in Inorganic Chemistry. Lectures on topics of current interest in inorganic chemistry. Consult division office for details in any particular quarter. (2 cr per qtr; prereq 104) Staff

For Graduate Students Only

203. Advanced Inorganic Chemistry I: Atomic Structure and the Chemical Bond

204. Advanced Inorganic Chemistry II: Thermodynamics and Kinetics of Inorganic Chemical Reactions

205. Advanced Inorganic Chemistry III: Survey of the Chemistry of the Transition Metals

206. Advanced Inorganic Chemistry IV: Survey of the Chemistry of the Nontransition Elements

207. Advanced Inorganic Chemistry V: Applications of Ligand Field Theory

211-212-213.‡ Selected Topics in Inorganic Chemistry

220-221-222.‡ Advanced Inorganic Chemistry Laboratory Methods

234-235-236.‡ Seminar: Modern Problems in Inorganic Chemistry

260. General Survey of Inorganic Chemistry

301-302-303.‡ Research in Inorganic Chemistry

Organic Chemistry (OrCh)

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

16. Carbon Compounds. (4 cr; prereq GeCh 5, 15 or 25)

17. Carbon Compounds Laboratory. Laboratory course, to accompany OrCh 16. (1 cr; prereq 16 or ¶16)

61. Elementary Organic Chemistry. Important classes of organic compounds, both aliphatic and aromatic, together with some heterocyclic compounds. Laboratory work includes the preparation of typical substances. (5 cr; prereq GeCh 5 or 25 or equiv; 3 lect, 1 lab conf, 1 quiz, and 4 lab hrs per wk)

61H. Elementary Organic Chemistry. Important classes of organic compounds, both aliphatic and aromatic, together with some heterocyclic compounds. Laboratory work includes the preparation of typical substances. (5 cr; prereq GeCh 5 or 25 or equiv, chemistry major [or permission]; 3 lect, 1 lab conf, 1 quiz, and 4 lab hrs per wk)

62. Elementary Organic Chemistry. Important classes of organic compounds, both aliphatic and aromatic, together with some heterocyclic compounds. Laboratory work includes the preparation of typical substances. (5 cr; prereq 61 or 61H; 3 lect, 1 lab conf, 1 quiz, and 4 lab hrs per wk)

62H. Elementary Organic Chemistry. Important classes of organic compounds, both aliphatic and aromatic, together with some heterocyclic compounds. Laboratory work includes the preparation of typical substances. (5 cr; prereq 61 or 61H, chemistry major [or permission]; 3 lect, 1 lab conf, 1 quiz, and 4 lab hrs per wk)

63. Elementary Organic Chemistry. Lecture course. (3 cr; prereq 62 or 62H; 63 is prerequisite to all other advanced courses in organic chemistry; 3 lect per wk)

63H. Elementary Organic Chemistry. Lecture course. (3 cr; prereq 62 or 62H, chemistry major [or permission]; 63 is prerequisite to all other advanced courses in organic chemistry; 3 lect per wk)

65. Elementary Organic Chemistry Laboratory. Reactions of typical functional groups and introduction to chemical methods of organic qualitative analysis. (4 cr; prereq 63 or ¶63; course 65 replaced course 64 in 1966 and is prerequisite to all advanced courses in organic chemistry; 8 lab, 1 lect, and 1 conf hrs per wk)

96-97-98. Senior Thesis. A written final senior thesis report is required. (Cr ar; prereq ‡, 4th yr)

103. Spectral Methods for Organic Qualitative Analysis. Practical application of nuclear magnetic resonance and infrared spectral analysis to solution of organic problems. (3 cr; prereq 65)

109. Intermediate Organic Chemistry. Introduction to various aspects of physical organic chemistry. (3 cr; prereq 63 and PCh 102 or ‡)

139. Advanced Organic Chemistry Laboratory Work. Selected laboratory synthetic problems, which may include original work. Includes considerable individual instruction. (2-5 cr; prereq 65; 6-15 hrs lab work ar)

142. Chemistry of Natural Products. Biosynthesis of secondary natural products with emphasis on alkaloids, terpenes, and acetogenins. (3 cr; prereq 63; offered 1969-70 and alt yrs)

143. Chemistry of Natural Products. Steroidal hormones, their isolation, proof of structure, synthesis, and action. (3 cr; prereq 63; offered 1970-71 and alt yrs)

144. Heterocyclic Compounds. Typical classes of heterocyclic compounds, their chemical and physical properties and uses, synthesis. (3 cr; prereq 63; offered 1970-71 and alt yrs)

165. Organic Qualitative Analysis. Reactions of typical functional groups and introduction to chemical methods of organic qualitative analysis. (4 cr, §65; prereq 63; 8 lab and 2 conf hrs per wk)

For Graduate Students Only

201, 202, 203.*‡ Organic Chemistry Seminar

231. Advanced Organic Chemistry

232.* Stereochemistry

233.* Physical Organic Chemistry

234.* Advanced Organic Chemistry

235.* Theoretical Organic Chemistry

238. Introduction to Research

240. Introduction to Research

250. Theoretical Organic Chemistry

251. Theoretical Organic Chemistry

261. General Survey of Organic Chemistry

301, 302, 303.*‡ Research in Organic Chemistry

Physical Chemistry (PCh)

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

90. Introduction to the Principles of Physical Chemistry. Designed especially for biological concentrators minoring in biochemistry. (3 cr; prereq Math 10 or equiv and 1 yr general chemistry and 1 yr college physics)

91-92-93. Special Topics in Physical Chemistry. A survey of special topics in physical chemistry with emphasis on areas of current research. Designed primarily for third- and fourth-year chemistry majors. (2 cr per qtr; prereq 103 or 108)

96-97-98.‡ Senior Thesis. A written final senior thesis report is required. (Cr ar; prereq #, 4th yr)

101. Physical Chemistry. Basic thermodynamics. (4 cr; prereq 1 yr college chemistry, Phys 9 or ¶Phys 9, or 6 with #, Math 31 or 44)

102. Physical Chemistry. Atomic and molecular structure, elementary quantum mechanics. (4 cr; prereq 1 yr college chemistry, Phys 9 or ¶Phys 9, or 6 with #, Math 31 or 44)

103. Physical Chemistry. Electrolytic solutions, electrochemistry, theory of liquid and solid states. (4 cr; prereq 104)

104. Physical Chemistry. Statistical mechanics and reaction kinetics. (4 cr; prereq 101 and 102)

105. Analysis of Data. Statistical and numerical treatment of physicochemical measurements. (1 cr; prereq 101 or 102 or 108)

106A-B. Laboratory. Measurement and interpretation of physicochemical properties. (1, 2, or 3 cr; prereq 105)

107-108. Elementary Physical Chemistry. Brief general survey. 107 covers chemical thermodynamics; 108 includes kinetics, statistical mechanics, and molecular structure. (3 cr per qtr; prereq 1 yr college chemistry, Phys 9 or ¶Phys 9 or 6 or #, Math 25A or 31 or 44, or 40 with #)

112. Atomic and Molecular Structure. Introduction to quantum mechanics with application to structure and bonding. (4 cr; prereq minimum of 2 qtrs physical chemistry)

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

117. Fundamentals of Reaction Kinetics. Analysis of rate measurements, collision theory, transition state theory, chain reactions. (4 cr; prereq minimum of 2 qtrs physical chemistry)

124-125-126. Statistical Mechanics. Statistical thermodynamics, irreversible processes, kinetic theory, chemical kinetics. (4 cr per qtr; prereq 101 plus 1 addtl qtr physical chemistry)

127. **Physical Chemistry of Polymers.** Molecular weight distribution, statistical mechanics of polymer solutions, network polymers, viscosity, light scattering, viscoelastic behavior. (3 cr; prereq 104 or ‡; offered spring 1970 and alt yrs)

129. **Polymer Laboratory.** Osmotic pressure, viscosity, and light scattering measurements for the determination of molecular weight; phase equilibria in polymer solutions; elastic and viscoelastic behavior of polymers; polymerization kinetics. (2 or 3 cr; prereq 104 or ‡; offered spring 1971 and alt yrs)

140-141-142. **Molecular Spectroscopy.** An examination of various types of molecular spectroscopy from the standpoint of how structure information is obtained from spectra. (3 cr per qtr; prereq 102 or equiv for 140)

For Graduate Students Only

204-205-206. **Quantum Mechanics**

214. **Kinetics and Mechanism of Enzymic Reactions**

215. **Physical Chemistry of Proteins**

217. **Physical Methods in Biopolymer Research**

221-222-223.‡ **Seminar: Radiation Chemistry**

250-251-252.‡ **Seminar: Physical Chemistry**

253-254-255.‡ **Seminar: Molecular Spectroscopy**

256-257-258.‡ **Seminar: Theoretical Chemistry**

259-260-261.‡ **Seminar: Photochemistry**

263. **General Survey of Physical Chemistry**

265-266-267.‡ **Seminar: Magnetochemistry**

268-269-270.‡ **Seminar: Statistical Mechanics**

271-272-273.‡ **Seminar: Physical Chemistry of Biological Systems**

274-275-276.‡ **Seminar: Quantum Mechanics**

277-278-279.‡ **Seminar: Physical Chemistry of Polymers**

290-291-292.‡ **Selected Topics in Physical Chemistry**

301-302-303.‡ **Research in Physical Chemistry**

Civil Engineering and Hydraulics (CE)

GENERAL COURSES

1. **Civil Engineering Orientation.** Fundamentals of civil engineering practice presented by professional engineers and members of the faculty. (1 cr)

100. **Contracts and Specifications.** Synopsis of the law of contracts, sales, agency, negotiable instruments, real property, personal property, partnerships, corporations, insurance contracts, workmen's compensation, labor law, mechanics' liens, government construction contracts, and torts with applications to the performance of engineering and construction contracts. (3 cr; prereq 3rd yr or grad or ‡)

102. Building and Construction Contracts. Contracts with public authorities; the invitation, bid award; potential problems. Private construction. Legal problems in construction; contract administration. (3 cr; prereq 100 or ¶100)

121. Applications of Linear Programming. Classical and modern methods of mathematical model formulation for operations analysis, with specific emphasis on problems encountered in civil engineering. Various methods of solution for specific classes of problems. Introduction to dynamic programming applications. (3 cr; prereq Math 32 or equiv)

125. Introduction to Computer Applications in Civil Engineering. Basic instruction in computer programming and utilization of digital computers in the solution of civil engineering problems. Execution of actual problems in surveying, structures, hydromechanics, etc., in cooperation with the University Computer Center. (3 cr; prereq 64A, 81, 160, or ‡; 2 lect and 3 lab hrs per wk)

133-134-135. Senior Research Projects Course. Qualified senior students working individually or in small groups on a research or specialized study project under the guidance of a faculty member. Project may be either analytical or experimental in nature. (3 cr per qtr; prereq approval of faculty adviser)

169. Public Works Engineering. Engineering phases and relationships of public works. Historical survey. Federal, state, and local administration problems. Present trends and practices. The need for adequate public planning design and construction. Responsibilities of the engineer. Typical problems. (3 cr; prereq 52)

197-198-199.‡ Advanced Design and Analysis in Civil Engineering. Special studies in planning, design, or analysis of complex civil engineering systems. Individual laboratory research problems, literature studies and reports supervised by senior staff. (1-3 cr; prereq approval of faculty sponsor)

HYDROMECHANICS, HYDROLOGY, AND HYDRAULIC ENGINEERING

101A. Fluid Mechanics. Fluid statics and dynamics for liquid and gases. Kinematics of fluid flow, viscous effects and introduction to incompressible and compressible duct flow. (4 cr, §Aero 100A; prereq Math 32; 3 lect and 3 lab hrs per wk)

160. Engineering Hydraulics I. Uniform and varied flow in artificial and natural open channels. Analysis of closed conduit pipe and culvert flows. Characteristics and applications of centrifugal pumps. Flow measurements in pipes and open channels. Applied problems pertaining to spillways and outlet works. (4 cr; prereq 101, or Aero 100A with ‡; 3 lect and 3 lab hrs per wk)

161. Hydrology. Basic data and methods available for analysis of precipitation and runoff, including stream flow, groundwater, infiltration, unit hydrographs, flood frequencies, flood routing, and probable maximum floods. (3 cr; prereq 160 or ¶160 or ‡; 2 lect and 3 lab hrs per wk)

162. Engineering Hydraulics II. Topics related to civil engineering hydraulic structures and systems; fluid forces and their dimensionless numbers, steady and unsteady forces on hydraulic structures, gravity waves, stratified flows and sediment transport. (3 cr; prereq 101)

163. Groundwater Hydraulics. Flow of fluids through porous media including fundamental equations, potential flow theory and approximate solutions; application of these theories to seepage through and under dams and cofferdams, wells, well point systems and stratified media. (3 cr; prereq 101A or ‡)

164. Introduction to Water Resources Management. Availability and requirements for water; economic, social, political, and engineering factors influencing distribution of water to various needs. Typical problems. (3 cr)

166.* Water Power. Stream flow and water power estimates. Storage problems. Analysis, design, and selection of water power structures and equipment. Types and purposes of dams. Turbine analysis. Transmission lines. Cost and value of water power. Typical problems, inspection trips. (3 cr; prereq 161; 2 lect and 4 lab hrs per wk)

167. Hydraulic Measurements. Laboratory and field methods and instruments for measurements of hydraulic pressure, velocity, and discharge. (3 cr; prereq 101 or ‡)

168. Hydraulic Pumps and Turbines. Introductory theory of hydraulic pumps, turbines, motors, and transmissions including energy concepts, drag and lift of hydrofoils, and limitations of cavitation. (3 cr; prereq 101 or ‡)

184.* Open Channel Hydraulics I. Theory of steady uniform and varied flow with applications to hydraulic structures, channels and channel transitions, hydraulic jump, etc. Computations of water surface profiles, forces on structures, energy dissipators. (3 cr; prereq 101 or ‡)

185.* Open Channel Hydraulics II. Continuation of steady varied flow. Theory of spatially varied flow and unsteady varied flow with applications to spillways, waves and surges in channels, longitudinally varied discharge, flood waves, moving hydraulic jump, etc. (3 cr; prereq 184 or ‡)

186.* Mechanics of Similitude and Dimensional Analysis. Applications of dimensional analysis to hydraulic problems and to similitude. Theory of models, conditions for similarity in the case of hydraulic structures, elastic structures, aircraft, ships, waves, etc. (3 cr; prereq 101 or ‡)

187. Intermediate Fluid Mechanics. One- and two-dimensional flow of an ideal fluid, energy and momentum relations, fluid forces, boundary layer theory, separation and cavitation, hydrofoils. (3 cr; prereq 101, or Aero 100A with ‡)

188.* Incompressible Potential Flow. Potential flow methods and their application to engineering problems. (3 cr, §Aero 104; prereq 187 or ‡)

189.* Incompressible Boundary Layer Flow. Some applications of boundary layer methods to engineering problems. (3 cr, §Aero 101A; prereq 187 or ‡)

190. Hydraulic Transients. Hydraulic transients encountered in coastal and water resource engineering, including oscillatory, solitary, tidal, and flood waves; water hammer; hydraulic jumps; forced vibration of gates and other components of hydraulic structures; and hydrodynamic flutter. (3 cr; prereq 160 or ‡)

191-192-193. Advanced Hydraulic and Hydrologic Problems. (1-3 cr per qtr; prereq approval of faculty sponsor)

194-195-196.* Advanced Hydraulic Laboratory. Experimental and analytical studies of hydraulic phenomena relating to fluid measurement, pumps, spillways, stilling basins, wave absorption, flow transients, and other selected topics. (2 cr per qtr; prereq approval of faculty sponsor; 6 lab hrs per wk)

SANITARY ENGINEERING

170. Water Supply. Sources of water supply; quality of water, collection, distribution, and water purification; test methods. Laboratory problems in analysis and design. Inspection trips. (3 cr; prereq 160 or ‡; 3 lect and 3 lab hrs per wk)

171. Sewerage and Waste Water Treatment. Sources and quantities of waste water; sanitary, storm, and combined sewer systems; materials and methods of construction; physical, chemical, and biological characteristics of waste water. Disposal by dilution. Domestic and industrial waste treatment. Laboratory problems in analysis and design. Inspection trips. (3 cr; prereq 161, 170 or ‡; 3 lect and 3 lab hrs per wk)

172. Sanitary Engineering Laboratory. Biological, bacteriological, physical, and chemical analyses of water, waste water, air, coagulant chemicals, disinfectants, waste water sludge, etc. (3 cr; prereq 171 or grad; 8 lab hrs per wk)

173.* Sanitary Engineering Problems (Water). (Supplements 170) Investigations of problems in water supply. Collection, distribution, and purification. Economic studies. (3 cr; prereq 170 or grad)

174.* Sanitary Engineering Problems. (Supplements 171) Investigations of problems in waste water treatment. Stream pollution control, stream standards, economic studies of various types and degrees of treatment. (3 cr; prereq 171 or grad)

175.* Industrial Waste Disposal. Investigation of quantity and quality characteristics of industrial wastes. Problems with separate treatment or disposal to municipalities. Legal responsibility and ordinances. Determination of equitable charges. Economic studies. (3 cr; prereq 174 or grad)

176*-177*-178.*‡ Seminar: Sanitary Engineering. Reports and discussions on selected topics in the field of sanitary engineering with presentations by off-campus lecturers. (1 cr per qtr; required of grad students majoring in sanitary engineering; prereq 171 or grad; 1 rec hr per wk)

179.* Ground Water and Surface Water Quality Problems. The study of water resources quality. Water quality as related to various beneficial uses. Physical, chemical, and microbiological characteristics of pollutional components. Pollution and recovery characteristics of surface and ground waters. (3 cr; prereq 171; 3 lect and 2 lab hrs per wk)

180.* Solid Waste Disposal Problems. Engineering factors in the collection and final disposal of solid wastes from urban areas. Regulations, economic factors, and health and aesthetic considerations. Inspections and problems. (3 cr; prereq 171; 3 lect and 3 lab hrs per wk)

181. Chemical and Biological Aspects of Sanitary Engineering I. Principles of biochemistry and microbiology pertinent to an understanding of the microbiological growth phenomena in waste water treatment processes and in natural waters. (3 cr; prereq GeCh 15, 172 or ‡)

182. Chemical and Biological Aspects of Sanitary Engineering II. Analytical approach to biological purification of waste water based on mass transfer and growth rate considerations. (3 cr; prereq 181 or ‡)

STRUCTURAL ENGINEERING

78-79-80. Elementary Structural Design for Architects. Elementary structural analysis and design of frame buildings in steel and timber. Reinforced concrete for buildings and foundations. (3 cr per qtr; prereq MM 93)

81. Analysis of Structural Elements. Response of tension members, beams, columns, beam-columns, and plates to static and dynamic loads. Linear and nonlinear behavior associated with material properties. Numerical methods. Composite-material elements. (4 cr; prereq MM 35, Math 32; 3 lect, 2 lab hrs per wk)

82-83. **Analysis of Structural Systems I, II.** Preliminary design considerations. Matrix methods of analysis of statically determinate and statically indeterminate structures. Linear and nonlinear behavior. Buckling. Dynamic loads. Deformation analysis. Thin-walled structures. Computer methods. (4 cr per qtr; prereq 81 or MM 37; 3 lect, 2 lab hrs per wk)

126. **Approximate Methods of Structural Analysis I.** Numerical determination of slope, moment, shear and deflection in statically determinate and statically indeterminate structural members that have nonuniform deformation properties. Numerical methods for obtaining influence lines for statically indeterminate structures with variable properties. Rapid determination of elastic and inelastic buckling loads and combined bending and axial loads in beams and frames by approximate methods. (3 cr; prereq 83)

136. **Design of Metal Structures.** Elastic and plastic philosophies of design and related properties of structural metals. Design of tension members, columns, beams, trusses, buildings, and bridges. Connections. Plastic design. (4 cr; prereq 81; 3 lect, 2 lab hrs per wk)

137. **Structural Laboratory.** Lectures, demonstrations, and laboratory exercises on experimental stress analysis of structural elements and systems under static and dynamic loading. Students plan and execute a small experimental project. (3 cr; prereq 81)

139. **Structural Dynamics I.** Elastic response of lumped and distributed parameter systems to dynamic loading. Problem formulation, and methods of solution for single-degree-of-freedom systems, n-degree-of-freedom systems, and infinite degree of freedom systems with specific applications in structural engineering. (3 cr; prereq 83, MM 193, or ‡)

141. **Design of Reinforced Concrete Structures.** Working stress and ultimate load philosophies of design and their relation to physical properties of steel and concrete. Design of continuous beams, columns, slabs, footings. Relation of code provisions to field and laboratory measurements. (4 cr; prereq 81; 3 lect, 2 lab hrs per wk)

142-143-144.‡ **Advanced Structural Design I, II, III.** 142: Design of shells, arches, storage vessels, retaining walls. 143: Cable-supported and unconventional structures. Computer-aided design. Special methods of analysis. 144: Prestressed concrete. Composite and orthotropic construction. Yield-line determination of ultimate load-carrying capacity of slabs. (3 cr per qtr; prereq 83)

145. **Structural Design by the Ultimate Load Theory.** Plastic design of steel structures with applications to continuous beams, portal frames, and gabled frames. Investigation of deflections at ultimate load. Limit design of reinforced concrete frameworks. (3 cr; prereq 136, 141)

SOIL MECHANICS AND CONSTRUCTION MATERIALS

53. **Elements of Soil Mechanics.** Physical properties of soils; soil formation; stress distribution; shearing strength. Laboratory identification and compaction tests. (3 cr; 2 lect and 3 lab hrs per wk)

146. **Concrete and Concrete Materials.** Design and control of concrete mixtures, air-entrained concrete, properties of concrete, constitution of cement, and construction practice. (3 cr; prereq 53; 2 lect and 4 lab hrs per wk)

147. Foundations. Earth pressure theories of Rankine, Coulomb, Poncelet. Flexible bulkheads. Soil bearing power. Footings. Piles of steel, timber, and concrete. Pile driving formulas. Driving and handling stresses. Cellular cofferdams, single-wall cofferdams. Caissons. Bridge piers. Port structures and installations. (3 cr; prereq 81, 53 or ‡)

148.* Special Studies in Concrete Materials. Short laboratory research studies. (2-3 cr; prereq 146)

151.* Advanced Highway Laboratory. Special experimental studies of highway materials. (3 cr; prereq 52; 8 lab hrs per wk) Thomas

153. Soils in Highway Engineering. Classification, soil maps, frost action, surveys, physical tests, compaction, design of graded mixes, and soil stabilization. (3 cr; prereq 53)

154. Design of Highway and Airport Pavements. Advanced studies of theories and practices in the design of rigid and flexible pavements. Strength tests of subgrades and base courses. Pavement evaluation. (3 cr; prereq 53)

157. Slope Stability. Permeability, seepage, dewatering, analysis of slope stability problems. (3 cr; prereq 53 or ‡)

159. Bearing Capacity. Consolidation, stress distribution, settlement analysis, bearing capacity. (3 cr; prereq 53)

TRANSPORTATION ENGINEERING AND LAND DEVELOPMENT

51-52. Highways and Pavements. Elements of highway planning, economics, finance, location, design, construction, and maintenance. Field trips and laboratory testing of materials. (3 cr per qtr; prereq 53, 61A; 2 lect and 3 lab hrs per wk)

61A. Survey Engineering. The planning, design, and execution of field control survey systems to determine the horizontal and vertical position of points on the earth for mapping, engineering projects, property boundaries and construction. Field problems in use of equipment. (3 cr; prereq Math 22A or equiv; 2 lect and 4 lab hrs per wk)

63A. Elements of Land Development. Study of land ownership and title transfers, property rights, description and location of property lines; land use and development procedures; study and analysis of maps, photographs, and photogrammetric equipment as data sources for land use studies and engineering design. (3 cr; prereq Math 15 or Math 21A or ‡; 2 lect and 3 lab hrs per wk)

64A. Engineering Geometronics. The geometric design of engineering projects; horizontal and vertical curves; grades; fitting of structural elements to the topography; earthwork and drainage analysis; detailed site plans for construction; computations for construction layout; layout. (3 cr; prereq 61A; 2 lect and 4 lab hrs per wk)

111. Land Surveying. Study of Minnesota Public Land Survey. Federal and state laws governing resurveys, registered land surveys, and subdivision plats. Court decisions and legal principles involving boundary line determinations. Interpreting and writing deed descriptions. (3 cr; prereq 63A or ‡)

112. Aerial Surveying and Photogrammetry. Theory and methods of making planimetric and topographic maps by photogrammetric methods with second-order stereoscopic plotters. Control nets, state coordinates, and astronomy as used in large-scale mapping projects. (3 cr; prereq 63A or ‡; 2 lect and 3 lab hrs per wk)

113. **Land Planning and Subdivision Design.** The study and analysis of land planning and development problems. Economics and design of road patterns, lot and block layout, drainage, utilities, etc. Design, computation, and preparation of record plats. (3 cr; prereq 63A or ‡; 2 lect and 3 lab hrs per wk)

130. **Introduction to Transportation Planning.** Techniques and processes used in solving transportation problems of urban areas. Collection and characteristics of base year data, formulation of mathematical models to simulate existing travel patterns, forecasting procedures and evaluation of different transportation systems. (3 cr; prereq ‡)

152.* **Highway Design.** Geometric design of rural highways. Design of intersections, interchanges, and freeways. (3 cr; prereq 52)

156. **Highway Traffic Engineering.** Characteristics of vehicle and driver. Traffic surveys. Stream characteristics. Traffic control. Accidents and their prevention. (3 cr; prereq 52)

158. **Airport Design.** Field layout, capacity, drainage, and studies of bases and surfaces for aprons, runways, and taxiways. (3 cr; prereq 52)

For Graduate Students Only

210. Seminar: Theory of Traffic Flow

211. Seminar: Urban Traffic Operations

212. Seminar: Freeway Traffic Operations

215. Seminar: Advanced Transportation Planning

227, 228. Approximate Methods of Structural Analysis II, III

234*-235.* Advanced Theory of Structures

236.* Shell Structures

240-241-242. Advanced Structural Laboratory

244. Structural Dynamics II

245. Structural Design for Dynamic Loads

246. Foundation and Harbor Engineering

247*-248*-249.* Seminar: Structures

251-252.* Advanced Soil Mechanics Laboratory

261.* Water Plant Design

262.* Waste Water Plant Design

264. Sanitary Engineering Unit Operations

276.* Advanced Sanitary Engineering (Water)

277.* Advanced Sanitary Engineering (Waste Water and Industrial Wastes)

280*-281*-282.* Civil Engineering Research

287. Fluid Turbulence

289. Mechanics of Sediment Transport

293-294-295. Hydrodynamics of the Boundary Layer

296-297-298.‡ Special Topics in Hydrodynamic Theory

Ecology and Behavioral Biology (EBB)

50w. Introduction to Ecology. Interrelationships between environmental influences and plants and animals, including man: population growth and regulation; the nature, organization, and development of ecological systems. The role of man in the biosphere. (3 cr; open to jrs and above, not open to biology majors) Brook

51s. Ecology and Man. Man's impact on and his exploitation of the environment. Stresses human limits in terms of population, natural resources and waste disposal. (3 cr; prereq Ecol 50, Biol 80 or ‡) Megard

Electrical Engineering (EE)

30-31. Circuit Analysis. 30: Steady-state and transient response of linear passive circuits under dc, step, and sinusoidal excitation. 31: Steady-state ac analysis; instantaneous and average power. Complex frequency; natural and forced response. Magnetically coupled circuits. (3 cr per qtr; prereq Phys 8 or 22T or 23, Math 31 or ¶Math 31; 3 lect hrs per wk)

30A-31A. Electrical Engineering Laboratory. Laboratory to accompany 30-31. (1 cr per qtr; prereq ¶30-31; 2 lab hrs per wk)

46. Circuits. Analysis of linear passive circuits; natural and forced response. Steady-state ac analysis; resonance. (4 cr, §30, §30A; not for EE majors; prereq Phys 23 or 23T, Math 32 or ¶Math 32; 3 lect and 2 rec or lab hrs per wk)

47. Electronics. Network theorems; two-ports, active device models; vacuum diodes, semiconductors; amplifiers, nonlinear devices; logic circuits. (4 cr; not for EE majors; prereq 31 or 46; 3 lect and 2 rec or lab hrs per wk)

64-65. Electronics I-II. 64: Introduction to physical principles of electronic devices; electrical properties of metals, insulators, and semiconductors. Semiconductor, vacuum, and gaseous devices; modeling. 65: Piecewise linear and incremental models, biasing, operating characteristics of active devices in single-stage circuits; applications of diodes for rectification, clipping, and clamping. (4 cr per qtr; prereq 31, Phys 50T or ¶Phys 50T; 3 lect and 2 rec hrs per wk)

64H-65H. Electronics I-II. (3 cr per qtr; prereq Δ, ¶94H-95H; 3 lect hrs per wk)

66. Nonlinear Electronic Circuits. Nonregenerative switching circuits, diode and transistor logic circuits; multivibrators, oscillators. (4 cr, §118; prereq 65, 107 or ¶107; 3 lect and 2 rec hrs per wk)

66H. Nonlinear Electronic Circuits. Honors course. (3 cr; prereq Δ, ¶96H)

74-75. Electromagnetic Fields I-II. Electrostatic, magnetostatic, and electromagnetic field theory based upon the fundamental experimental laws and leading to applications of Maxwell's equations. (4 cr per qtr; prereq Phys 23 or 23T, Math 33 or ¶Math 33 with ‡; 3 lect and 2 rec hrs per wk)

74H-75H. Electromagnetic Fields. (3 cr per qtr; prereq Δ, ¶94H-95H; 3 lect hrs per wk)

76. Electromagnetic Fields III. Applications of Maxwell's equations. Transmission lines, wave propagation, antennas and radiation. (3 cr; prereq 75)

76A. Electromagnetic Fields Laboratory. (1 cr; prereq 86, ¶76; 2 lab hrs per wk)

84-85-86. Junior Electrical Engineering Laboratory. Experimental study of electronic circuits, electromagnetic fields and linear systems. (2 cr per qtr; prereq 31A, ¶64-65 and Engl 85A-B for 84-85...66 or ¶66, 75, 85, 107 or ¶107 for 86; 1 conf and 3 lab hrs per wk)

94H-95H-96H. Electrical Engineering Honors Course. Special studies for third-year students in EE honors program. (4-4-3 cr, §84-85-86; prereq △)

99A-B-C. Special Investigations. Undergraduate studies of approved topics, theoretical or experimental in nature. (Cr ar; prereq approval of faculty sponsor)

101-102. Summer Engineering Employment. Summer work of not less than 360 hours per summer in an engineering field. Requires a technical report. (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)

107-108. Linear System Analysis. Development of time-invariant linear models for electrical, mechanical, thermal, and acoustic systems; analysis of the models in time and frequency domains. Applications of transform techniques to linear systems. Introduction to feedback systems. Analog computer simulation. Spectral analysis, correlation, noise, and sampling. (3 cr per qtr; prereq 31, Math 60A; 3 lect hrs per wk)

107H-108H. Linear System Analysis. Honors course. (3 cr per qtr; prereq △, ¶95H-96H)

110. Electromechanics. Energy considerations in electromechanical devices; linear and nonlinear analysis of electromechanical energy converters; characteristics of specific rotary converter types obtainable from a generalized rotating machine. (3 cr; prereq 75, 108 or ¶108, MM 36; 3 lect hrs per wk)

110A. Electromechanics Laboratory. (1 cr; prereq 86, ¶110; 2 lab hrs per wk)

117. Linear Electronic Circuits. Electronic functions, device limitations, and biasing stability; frequency effects in single-stage, cascaded, and tuned amplifiers; power amplifiers. Introduction to design considerations. (3 cr; prereq 65, 108 or ¶108; 3 lect hrs per wk)

117A. Electronic Circuits Laboratory. (1 cr; prereq 86, ¶117; 2 lab hrs per wk)

119. Electrical Engineering Materials. Electric, magnetic, and dielectric properties of materials as related to devices used in electrical engineering. (3 cr; prereq 76, Phys 50T)

127A-B. Network Synthesis. Description of linear networks in the time and frequency domains. Properties of two- and three-element-kind networks. Approximation and realization problems in network synthesis. Design of RC, RL, LC, and RLC networks to realize driving point and transfer functions and their applications. Special topics assigned. (4 cr per qtr; prereq 108 or ‡; 3 lect and 2 lab hrs per wk)

128A-B. Communications. Theoretical and laboratory study of selected topics in electric communications. Spectral analysis; modulation theory and the effect of noise in modulation systems; multiplex systems, optimum filtering. (4 cr per qtr; prereq 108, Stat 90E; 3 lect and 2 lab hrs per wk)

129A-B. Control Systems. Analysis and applications of typical linear control elements, analysis and design of linear control systems in the frequency and time domains, using such techniques as Bode, Nyquist, and root-locus methods; analytic and graphical treatment of system stability. (4 cr per qtr; prereq 108, Math 60A, or ‡; 3 lect and 2 lab hrs per wk)

130A-B. Applications of Electromagnetic Theory. Maxwell's equations, Poynting vector, propagation and reflection of plane waves. Transmission lines, wave guides, and resonant cavities. Radiation, interference, and diffraction. Other selected topics. (4 cr per qtr; prereq 76 or equiv; 3 lect and 2 lab hrs per wk)

131A. Applied Electronics I. Multistage amplifiers; broad-band, feedback, tuned transistor amplifiers; noise in amplifiers. Analysis and design including laboratory investigation of design. (4 cr; prereq 117; 3 lect and 2 lab hrs per wk)

131B. Applied Electronics II. Charge-control analysis of nonregenerative and regenerative switching circuits. Tuned power amplifiers and oscillators. Parametric amplifiers. (4 cr; prereq 66, 131A; 3 lect and 2 lab hrs per wk)

134A-B. Direct Energy Conversion. Photoelectric, thermoelectric, thermionic, magnetohydrodynamic, and phase-change energy converters. Kinetic and transport properties of materials; interaction with electric, magnetic, thermal, and mechanical fields. Applications and limitations of typical converters. (4 cr per qtr; prereq 64, 76, ME 30; 3 lect and 2 lab hrs per wk)

135A-B. Principles of Computer Engineering. Analog and digital computers. Properties of computer elements and their limitations; control of computers. Basic analog, digital, and hybrid computer systems design for computation, simulation, and real-time control of automated processes. (4 cr per qtr; prereq 108; 3 lect and 2 lab hrs per wk)

138A-B. Electric Power Systems. Modern electric power system technology; response of rotating machines; complete electric power system: generation, transmission, distribution, and utilization. Balanced and unbalanced polyphase systems. Stability analysis of power systems. Digital computer applications to power system problems. (4 cr per qtr; prereq 108, 110; 3 lect and 2 lab hrs per wk)

141A-B. Physical Electronics. Physical principles underlying devices used in electrical engineering; elementary quantum and statistical mechanics, semiconductor properties, electron emission from surfaces, special topics of current interest. (4 cr per qtr; prereq 64 or ‡; 3 lect and 2 lab hrs per wk)

142H-143H-144H. Honors Project. Design project for fourth-year students in EE honors program. (3 cr per qtr; prereq △)

147A-B. Applied Electromechanics. Theory and application of translational and rotational electromechanical converters; transducers, sensors, and machines. Formulation of dynamic equations and methods of solution. Properties of materials, consideration of limitations they impose on device performance. (4 cr per qtr; prereq 108, 110, or ‡; 3 lect and 2 lab hrs per wk)

150. Dynamical Methods in Electrical Engineering. Lagrangian and Hamiltonian formulations of dynamics, with applications to electromagnetic systems. Lagrange's equations; dissipative forces; normal coordinates and small oscillations; Hamilton's equations; variational principles for discrete and continuous systems. (3 cr; prereq MM 36 or equiv, Math 33, or ‡; 3 lect hrs per wk)

151. Thermodynamic Methods in Electrical Engineering. Basic thermodynamic concepts and laws, with special application to electromagnetic systems. Energy, entropy, and thermodynamic potentials; application to electrically and magnetically polarizable materials, rigid or elastic; piezoelectricity, magnetostriction, thermoelectricity, reciprocal relations in reversible and irreversible processes. (3 cr; prereq 150 or ‡; 3 lect hrs per wk)

152. Statistical-Mechanical Methods in Electrical Engineering. Classical and quantum statistical mechanics, with applications to materials and problems of electrical engineering. Statistical ensembles, phase space. Liouville's theorem, the canonical ensemble, the partition function. Classical and quantum statistics. Relation between statistical mechanics and thermodynamics. Classical and quantum calculations of susceptibilities. (3 cr; prereq 150 or ‡; 3 lect hrs per wk)

153. Introductory Quantum Mechanics for Engineers. Principles of quantum mechanics for students with engineering background; intended as preparation for solid state materials or quantum electronics. Wave equation, operator formalism, angular momentum, perturbation theory. (3 cr; prereq grad standing or ‡; 3 lect hrs per wk)

167-168-169. Electromagnetic Theory. Fields and waves with attention to mathematical formulation. Maxwell's equations and boundary value problems. Plane waves, transmission lines, wave guides, and resonators. Microwave networks. Inhomogeneous, anisotropic, and ionized media. Diffraction theory and optical resonators. Parametric systems. (3 cr per qtr; prereq 76 and grad standing or ‡; 2 lect and 2 lab hrs per wk)

170. Linear Network Theory I. Properties and synthesis of the driving point and transfer functions of two- and three-element-kind networks. Theory of positive real functions. (3 cr; prereq 108 or equiv; 3 lect hrs per wk)

171-172. Linear Network Theory II-III. Relationship between parts of network functions. Approximation theory. Design of filters and pulse networks. Properties of reciprocal and nonreciprocal N-port networks. Synthesis of one-port and two-port networks using gyrators. (3 cr per qtr; prereq 170 or equiv; 3 lect hrs per wk)

173A-B-C. Semiconductor Properties and Devices. Principles and properties of semiconductor devices. Selected topics in quantum and statistical mechanics, crystal structures, semiconductor properties; transistor action and other device phenomena; influence of surfaces. Treatment of actual devices (such as bipolar and field-effect transistors). (3 cr per qtr; prereq grad standing or ‡; 3 lect hrs per wk)

178-179-180. Nonlinear Circuit Analysis. Semiconductor, ferromagnetic and ferroelectric devices as switching elements; regenerative switching circuits; digital logic circuits. Free and forced response of nonlinear circuits, amplitude and frequency of oscillatory circuits; phase-plane analysis. (3 cr per qtr; prereq 66, 117, or ‡; 3 lect hrs per wk)

186B. Stochastic Processes and Optimum Filtering. Stochastic processes, stationarity, independence, transformations of stochastic processes, ergodicity; correlation and power spectrum; the matched filter, the Wiener filter. (3 cr, §196; prereq grad in EE or ‡; 3 lect hrs per wk)

186C. Modulation Systems. Mathematical models and effects of noise on modulation systems such as AM, FM, and PCM. Telemetry and space communication systems. (3 cr; prereq 186B or 196; 3 lect hrs per wk)

187A-B. Information Theory and Coding. 187A: Binary arithmetic, logic; discrete information sources and channels, coding, the binary channel, and Shannon's second theorem. 187B: The continuous channel; error detection and correction codes, random coding; channels with feedback, the two-way channel. (3 cr per qtr; prereq Stat 90E or ‡; 3 lect hrs per wk)

190B-C. Digital Computer Systems. 190B: Boolean analysis and synthesis with practical logic circuits. Elementary sequential circuit theory and practical design techniques. Switching hazards and races. 190C: Modern computer structures; instruction classes, sequences, and microsequences. Elementary machine language programming. Arithmetic system design. Digital computer memory types and organizations. Input-output system design techniques. Techniques for reliability improvement. (3 cr per qtr; prereq 187A or ‡; 3 lect hrs per wk)

191A-B. Linear Active Networks. Network models of active devices. Analysis and synthesis of single-stage and cascaded amplifiers. Theory of feedback amplifiers and stability. Design of single loop and multi-stage feedback amplifiers. Bandpass amplifiers. (3 cr per qtr; prereq 170 or equiv, ¶171-172; 3 lect hrs per wk)

194A-B. System Analysis and Optimum Control. 194A: Linear algebra and matrix differential equations; linear system representation; stability of linear systems via Lyapunov's Direct Method; structure of linear systems; controllability and observability, sensitivity analysis of linear systems. 194B: Problem formulation and mathematical modeling; variational techniques and perturbation theory; mathematical programming; game theory; geometric theory of optimum control. (3 cr per qtr, §194-195; prereq 108 or equiv or ‡; 3 lect hrs per wk)

195A. Nonlinear System Design. Graphical approximate analytical and numerical techniques in nonlinear system analysis and design; stability of nonlinear systems. The use of computers in system design. (3 cr; prereq 194A or ‡; 3 lect hrs per wk)

196. Linear Stochastic Systems. Random signals in linear systems; linear filtering prediction and estimation; parameter estimation in identification problems; adaptive and learning systems. (3 cr, §186B; prereq 194A, Stat 90 or equiv, or ‡; 3 lect hrs per wk)

197A-B. Power System Analysis. Matrix representation of large power systems. Formulation and modification of network matrices. Numerical and computer methods of solution. Application to fault calculations, load-flow studies, stability studies, and loss formulas. (3 cr per qtr; prereq 170 or equiv, 194A, Math 184 or ‡; 3 lect hrs per wk)

For Graduate Students Only

200A-B. Solid State Physics

200C. Magnetic Properties of Solids

211-212-213. Advanced Topics in Network Theory

221-222-223. Seminar: Electric Power

227-228-229. Advanced Power-System Topics

233-234-235. Fluctuation Phenomena

242-243-244. Plasma Physics

245-246-247. Seminar: Plasma Physics

250A-B-C. Quantum Electronics

251A-B-C. Properties of Semiconductors

252A-B-C. Ferromagnetism and Related Phenomena

253A-B-C. Seminar: Quantum Electronics

254A-B-C. Seminar: Modern Optics

261A-B-C. Problems in Electromagnetism

262A-B-C. Seminar: Communication

263A-B-C. Seminar: Control Theory

264A-B-C. Seminar: Surface Physics

265A-B-C. Seminar: System Theory

267-268-269. Topics in Statistical Theory of Communication

272-273-274. Fundamentals of Acoustics

281-282-283. Seminar: Energy Conversion

290A. Models for Computing Machines

290B. Advanced Computer Systems

290C. Advanced Switching Theory

291-292-293. Seminar: Electronics

294-295-296. Advanced Control Topics

297A-B-C. Nonlinear Systems

English (Engl)

(College of Liberal Arts)

1f,w-2w,s-3f,s. Freshman English. A course in composition in which literature serves both as reading material and as the subject matter for writing. Not a course in the history of literature or in literary criticism. Satisfies Group A requirement for graduation. (3 cr per qtr, §Comp 1 or Engl A or 10H or Comm 1; prereq assignment to Category 1, 1A, or 2)

85. Technical Writing for Engineers. Theory and practice in technical and professional writing. (3 cr; prereq C or 3A or old 3B or 3; 3 rec hrs per wk) Haga and others

85A-B-C.† Technical Writing for Engineers. (See Engl 85) (1 cr per qtr; prereq C or 3A or old 3B or 3 and concurrent enrollment in a course designated by the major department and requiring preparation of technical reports) Haga and others

Geo-Engineering (GeoE)

(School of Mineral and Metallurgical Engineering)

1. Geo-Engineering Laboratory. The field of geo-engineering, and closely associated fields of mineral engineering, described and discussed in lectures and laboratories. (1 cr; 1 lect or lab hr per wk) Staff

13. Geo-Engineering Surveying. Mine and geologic field survey control systems. Triangulation, stadia, plane table. Compass surveys. Drill hole and joint system surveys. Point and stereo diagrams. Underground mine survey control, meridian transfer, gyrotheodolite, stope surveys, special problems. (3 cr; prereq CE 61A or ‡; 3 lect hrs per wk) Yardley

15. Survey Field Work. Open pit and underground surveying, shaft plumbing; stripping estimates; plane table work; solar and stellar observations; special problems. (2 cr; prereq 13; hrs ar) Yardley, Lacabanne

90-91-92.† Industrial Employment. Summer field work in mining geology, site investigation, rock mechanics, or allied fields for a period of 2 or more months. Character of the work to be approved by the school. Satisfactory record of employment and an acceptable report required. (1-3 cr per course; prereq ‡) Staff

111. Geological Exploration. Nongeologic ore determinants. Mineral law, taxation, liquidation value. Options and leases. Ore guides. Drilling, sampling, and combining theory. Geostatistics and concepts of risk elimination. (3 cr; prereq 3rd yr or ‡) Yardley

116. Geo-Engineering I. Geology and geotechnics in engineering problems. Significance of geologic factors in engineering. Geologic materials, defects, hazards, and engineering properties. Vibration damage criteria. Slope stability in rock, water effects, cleft-water pressure. Special problems. Case histories. (3 cr; prereq 1 qtr physical geology, jr yr or ‡) Yardley

117. Geo-Engineering II, Tunnel Technology. Tunneling systems, site problems. Analysis of stress and load. Design of linings and support. Materials handling. Planning. Special problems, case histories. (3 cr; prereq 132 or ‡)

131. Rock Mechanics I. Elementary analysis of stress and strain, mechanical behavior of rock, theories of rock failure and comminution, geological folding and faulting. (3 cr; prereq MM 37 or ‡)

132. Rock Mechanics II. Methods of in-situ stress determination, state of stress in rock masses, design of underground openings, subsidence, hydraulic fracturing, laboratory determination of rock properties, use of photoelastic polariscope. (3 cr; prereq 131)

133. Rock Mechanics III. Mechanical behavior of jointed rock masses, rock slope stability, influence of ground-water, rock bolting, design of tunnel supports, field determination of rock properties, analog and digital computer simulation in rock mechanics. (3 cr; prereq 131)

134. Rock Mechanics IV. Theories of blasting. Hydrodynamic theory of detonation. Calculation of explosion pressure. Design of blasting patterns. (3 cr; prereq MM 37) Starfield

151-152-153. Special Geo-Engineering Problems. Literature survey, research work or design study in geo-engineering problems. (cr ar; prereq 132; hrs ar) Staff

160. Geology and Technology of Nonmetallic Rocks and Minerals. Geologic and geographic setting, genesis, evaluation, exploitation, processing and marketing of industrial rocks and minerals. Emphasis is on unique problems associated with this group of mineral materials. (3 cr; prereq 4th yr; 3 lect hrs per wk) Yardley

161-162. Geo-Engineering Analysis. Comprehensive analysis of a geological engineering or rock mechanics problem. Involves the integration of concepts of rock and soil mechanics, geology and geophysics, mineral engineering and economics, in a specific problem chosen by the student and staff. Preparation of a professional report. (2 cr for 161, 3 cr for 162; prereq sr yr or ‡; 2 lab hrs per wk for 161, 6 lab hrs per wk for 162) Fairhurst, Yardley

180. **Geochemical Exploration.** Geochemical principles and techniques involved in the search for orebodies. Basic premises, primary and secondary distribution halos, Eh-pH, geochemical provinces. Interpretation of data, case studies. Laboratory work on colorimetric analysis of rock, soil, water. (3 cr; prereq sr or ‡; 2 lect and 2 lab hrs per wk) Yardley

185. **Selected Topics in Mineral Exploration.** Exploration programming in relation to theories of ore genesis. Analyses of effects of contract and lease requirements on decision and planning. Statistical analyses in ore estimates. Case histories. Special problems. (3 cr; prereq sr, grad; 3 lect hrs per wk; offered 1969 and alt yrs) Yardley

For Graduate Students Only

201-202-203.‡ Seminar: Geo-Engineering

204-205-206.‡ Seminar: Geo-Engineering

210. Advanced Engineering Design

212-213-214.‡ Geo-Engineering Research Problems

251-252. Advanced Rock Mechanics I, II

Geology and Geophysics (Geo)

(School of Earth Sciences)

INTRODUCTORY COURSES

1. **Physical Geology.** A first course in geology for science majors and an introduction to the scientific method and the nature of the earth for others. Survey of the main features of the physical world and of the processes that have formed them. Six to eight homework problems in special fields of geology and geophysics. (5 cr; prereq high school physics and chemistry recommended; 3 lect hrs, one 2-hr lab, 1 rec hr per wk)

2. **Historical Geology.** Evolution of the earth from its origin to the present, with special attention to the succession of physical and biological events of the past 600 million years. (4 cr; prereq 1 or 11; 3 lect hrs, one 2-hr lab per wk)

11. **Introductory Physical Geology.** (Intensive sequence) For prospective majors and others desiring more intensive course. (5 cr; prereq high school or college chemistry or ‡; 3 lect hrs, 1 rec hr, and two 2-hr labs per wk)

22. **Introductory Historical Geology.** (Intensive sequence) For prospective majors and others desiring more intensive course. (5 cr; prereq 11 or ‡; 3 lect hrs, 1 rec hr, and two 2-hr labs per wk)

62. **Introductory Mineralogy.** Introduction to crystallography, crystal chemistry, and mineralogy. Descriptive and determinative mineralogy. Study of minerals in natural rock systems. (5 cr; prereq 1 or 11 or ‡, 1 term college chemistry, Math 15; 3 lect and 6 lab hrs per wk)

63. **Introductory Structural Geology.** Primary and secondary structures of rocks, mechanics and modes of deformation, and structural techniques. Laboratory

exercises in three-dimensional representation and solution of selected structural problems. (3 cr; prereq 62 or 162 or ‡; 3 lect and 2 lab hrs per wk)

64. Introductory Sedimentology and Stratigraphy. Sedimentary processes and products with particular reference to modern sedimentary environments; principles of physical stratigraphy, correlation, facies, tectonic control, classification of stratigraphic units. (3 cr; prereq 62; 3 lect and 2 lab hrs per wk)

65. Introductory Field Geology. Methods used in geologic field work and their application to problems in Minnesota geology. (2 cr; required of and restricted to geology, geophysics, and geo-engineering majors; prereq 62, 63, or ‡; 1 lect-rec and 4 field hrs per wk)

99. Senior Research. Research on a geological or geophysical problem selected on the basis of individual interests and background, leading to a written report. Emphasis on independent data collecting (field, laboratory, or both), and analysis of results. (3 cr; prereq sr in geology or geophysics, ‡)

GEOLOGY OPTION A

100. Field Geology. Measurement of stratigraphic sections; study of fossils and igneous, sedimentary, and metamorphic rocks. Geological surveying on aerial photographs and topographic maps. Preparation of geologic maps and cross-sections. Study of structural and geomorphic features and geologic setting of mineral deposits. (9 cr; restricted to students majoring in geology, geophysics, and geo-engineering; prereq 63, 65, and ‡)

101. Field Geology in Minnesota. Study of representative field areas in Minnesota to include igneous, metamorphic, sedimentary, and glacial features. Field observations will be correlated by use of geologic maps. (2 cr; primarily for majors in Earth Science in College of Education; prereq 63)

103.* Problems in Geology and Geophysics. Individual research in laboratory or field problems at Upper Division or graduate levels. (1-6 cr; prereq ‡)

104.* Advanced General Geology. Considers central problems in modern and classical geology through seminar-type discussion, evaluation of professional publications, and special projects. (3 cr; open to science majors in any field with supplemental reading by nongeologists; prereq ‡; offered on demand)

105. Introduction to Paleontology. Introduction to morphology and classification of major fossil groups. (5 cr; prereq 2 or 22 or ‡)

106.* Invertebrate Paleontology. Detailed studies of morphology, classification, and ecology of selected groups of invertebrate fossils. (5 cr; prereq 105; 3 lect and 4 lab hrs per wk; offered on demand)

107. Vertebrate Paleontology I. Morphology, evolution, and stratigraphic distribution of fossil fish, amphibians, reptiles, and birds. (5 cr; prereq 105 or Zool 53 or 122)

108.* Vertebrate Paleontology II. Morphology, evolution, and stratigraphic distribution of fossil mammals. (5 cr; prereq 107 or Zool 53 or 122)

109C. Physical Geology for Teachers. An introduction to the scientific methods and the nature of the earth. Survey of the main features of the physical world and of the processes that have evoked them. (4 cr, §1, §11, §old Geol 1, §A; only for students holding degrees in education; prereq 1 term college chemistry or physics)

110. Sedimentology and Stratigraphy. Sedimentary processes and products with particular reference to modern sedimentary environments; principles of physical stratigraphy, correlation, facies, tectonic control, classification of stratigraphic units. (3 cr, §64 or equiv; not open to geology, geophysics, geo-engineering, mineral resources engineering, and metallurgy-materials science majors; prereq 62; 3 lect and 2 lab hrs per wk)

111.* Stratigraphy. Analysis of stratigraphy of typical and unique sequences of (a) Precambrian and Paleozoic rocks, or (b) Mesozoic and Cenozoic rocks. Methods of presentation of stratigraphic data. Term paper required. (3 cr; prereq 64 or 110)

112.* Micropaleontology. Biology and paleontology of microorganisms of geologic importance including Foraminifera, Radiolaria, flagellate Protista, Diatomaceae, Characea, Ostracoda, and conodonts. (3 cr; prereq 105)

115.* Geomorphology. A quantitative study of processes and resulting landforms in humid and arid regions of the earth's surface, in the ocean basins, and on the lunar surface. Topics covered include slope processes, weathering, fluvial erosion and deposition, shore processes, wind action, impact phenomena, and tectonics. Field trips; term paper or field project. (4 cr; prereq 2 or 22, Math 10 or 15 or ‡...62 and Math 22A recommended)

116.* Glacial Geology. Physics of modern glaciers. Glacial erosion and deposition. Stratigraphy and chronology of the Pleistocene in glaciated and nonglaciated areas. (3 cr; prereq 2 or 22)

117.* Pleistocene Geology. Problems in Pleistocene history of glaciated and nonglaciated areas, particularly North America, Europe, and the Mediterranean. Relation of Pleistocene climatic changes to soils, biogeography, and archaeology. Pollen analysis. (3 cr; prereq 116)

118.* Problems in Geomorphology. Detailed study of selected geomorphic processes. Emphasis will be on fluvial processes and arid region geomorphology. (3 cr; prereq 115)

119.* Glaciology. Theories of glacier flow. Internal structures and heat flow in glaciers. Reading assignments, problems, term paper. (3 cr; prereq Math 32 or equiv or ‡; offered 1970-71 and alt yrs)

120. Structural Geology. Primary and secondary structures of rocks, mechanics and modes of deformation, and structural techniques. Laboratory exercises in three-dimensional representation and solution of selected structural problems. (3 cr, §63 or equiv; not open to geology, geophysics, geo-engineering, mineral resources engineering, and metallurgy-materials science majors; prereq 62 or 162 or ‡; 3 lect and 2 lab hrs per wk)

121.* Advanced Structural Geology. Fundamental problems and genesis of secondary structural features; detailed analysis of typical examples. Comprehensive term paper required for graduate credit. (3 cr; prereq 63 or 120)

122C. Historical Geology for Teachers. An introduction to the origin of the earth, the physical evolution of its crust through geological time and the biological changes that occurred during its history. (4 cr, §old Geol 2, §B, §Geo 2, §22; only for students holding degrees in education; prereq 1 or 11 or 109C or ‡; laboratory, field work, and seminar)

125.* Sedimentary Geochemistry. Properties of bulk and adsorbed water. Phase relations from electrode measurements. Thermodynamic and kinetic implications of defective crystal structures. Stable isotope studies. (4 cr; prereq PCh 103 or ‡; 3 lect and 2 lab hrs per wk)

126.* Sedimentary Petrology. Mineralogy, textures, and structures of sedimentary rocks. Role of the tectonic framework. Differential effects of weathering and transport. Modern classification schemes. (4 cr; prereq 64 or 110 or ‡; 3 lect and 2 lab hrs per wk)

128. Limnology. Description and analysis of the events occurring in lakes, reservoirs, and ponds, beginning with their origins and progressing through a study of their physics, chemistry, and biology. Emphasis is placed on the interrelationships of these parameters, and on the effects of civilization on lakes. Laboratory, field trips. (4 cr, §Ecol 138; prereq GeCh 5 or equiv and ‡)

131. Ground Water Geology. Origin, occurrence, and movements of ground water. Characteristics of major aquifers and aquitards. Exploratory investigations. Hydrogeologic units and boundaries. Principles and theoretical aspects of recharge. Quality of ground water supplies. (3 cr; prereq 1 or 11, Math 23A, 1 qtr physics and chemistry, or ‡)

132. Analytical Geohydrology. Microphysics of flow through porous media; geological factors in aquifer performance; equations for ground water flow; analysis of pumping tests; potential theory in ground water flow; computer and analog models of aquifers; ground water basin analysis. (3 cr; prereq 131, Math 31 or 107A, CE 101A or equiv, or ‡)

GEOLOGY OPTION B

140.* Mineral Systems I. Basic and compound symmetry elements. Derivation and study of point groups, coordinate systems, crystal forms, lattices, plane groups, and space groups. Introduction to X-ray diffraction. Introduction to crystal chemistry and crystal structures. (3 cr; prereq 62 or ‡, trigonometry, 1 yr college physics and chemistry; 3 lect and 2 lab hrs per wk)

141.* Optical Mineralogy and Petrography. The behavior of isotropic and anisotropic media in polarized light. The optical properties of minerals and their determination. Introduction to petrography. Laboratory includes the use of the polarizing microscope, the study of rocks and minerals in hand specimen and in thin section. Lecture and laboratory. (4 cr; prereq 62 or ‡)

142.* Mineral Systems II: Petrology. Phase equilibria, mineral and rock associations, textures and structures developed through igneous and metamorphic processes. Laboratory and term paper. (3 cr; prereq 141, PCh 102 or 108, Math 31)

145.* Phase Equilibrium in Mineral Systems. Graphical and mathematical treatment of one-, two-, three-, and four-component systems. Includes the phase rule, open vs closed systems and effects of disequilibrium. (3 cr; prereq 141, PCh 108 or 103; offered 1970-71 and alt yrs)

146.* Igneous Petrology. Igneous processes in light of experimental data and theory. Discussion of classical studies of igneous rock associations. Term paper required. (3 cr; prereq 145; offered 1970-71 and alt yrs)

147.* Metamorphic Petrology. Metamorphic processes in light of experimental data and theory. Discussion of classical studies in metamorphism. Term paper required. (3 cr; prereq 146; offered 1970-71 and alt yrs)

149. Introductory Geochemistry. Application of solution chemistry to geologic problems. Solubility and stability of sedimentary and hydrothermal minerals. Ocean-water chemistry and the history of the atmosphere and oceans. Chemistry of ore-forming fluids and formation of hydrothermal ore deposits. (3 cr; prereq GeCh 6, PCh 101 or PCh 107 or ¶PCh 101 or ¶PCh 107)

150.* General Geochemistry. Introduction to some basic principles and data of geochemistry, origin and cosmic abundances of elements, structure and composition of the earth, and geochemistry of some major elements in the earth's crust and mantle. (3 cr; prereq PCh 102 or 108 or ‡)

151.* Nuclear Geology. Includes studies of radioactive decay schemes and nuclear properties of certain elements in geochronology and geochemical processes such as the origin of igneous rocks, continents, and the early history of the earth and the solar system. (3 cr; prereq 142, 150 or ‡; offered 1970-71 and alt yrs)

152.* Problems in Geochemistry. Selected topics in geochemistry. (2 cr; prereq 151 or ‡; offered 1969-70 and alt yrs)

155. Mineral Deposits. Nature and distribution of mineral deposits, and analysis of processes by which elements are concentrated in magmatic, hydrothermal, sedimentary, and surface environments. (3 cr; prereq 142 or ‡)

156. Geology of Mineral Deposits. Lecture and seminar course dealing with the major types of metal deposits and their regional tectonic setting. Detailed discussion of type examples — their structural setting, mineralogy, and genesis. Utilization of genetic concepts in mineral exploration. (4 cr; prereq 63 or 120, 142, 155 or ‡)

157. Mineral Fuel Deposits. Origin and distribution of petroleum and coal deposits: source materials, reservoir rocks and structures, stratigraphic distribution of important deposits. (3 cr; prereq 64 or 110, 63 or 120, or ‡)

160.* X-Ray Mineralogy. Physics of X rays. Diffraction of X rays by crystalline material. Description of x-ray powder instruments. The use of powder pattern for mineral identification and for mineralogical and crystallographical research. (3 cr; prereq 140 or ‡)

161.* Single Crystal X-Ray Diffraction. Introduction to the principles and practice of single crystal x-ray diffraction. Lattice and space group determination. Introduction to crystal structure determination. (2 cr; prereq 160 or ‡)

162.* Mineralogy. Introduction to crystallography, crystal chemistry, and mineralogy. Descriptive and determinative mineralogy. Study of minerals in natural rock systems. (4 cr, §62; not open to geology, geophysics, geo- or mineral resources engineering or metallurgy-materials science majors; open to majors in the College of AFHE and postgrad students in education; prereq 1 or 11 or ‡, 1 term college chemistry, Math 15; 3 lect and 6 lab hrs per wk)

163.* Electron Microprobe Analysis. Introduction to theory of electron optics, review of x-ray fluorescence. Electron microprobe analysis with mineral and pure element standards. (3 cr; prereq PCh 103 or Phys 51T or Geo 160 or ‡)

GEOPHYSICS

170A. Earth Physics I. Magnetic and gravity fields of the earth. (2 cr; prereq Phys 23T)

170B. Earth Physics II. Internal constitution and thermal history of the earth, geochronology. (2 cr; prereq Phys 23T)

171. Introduction to Earthquake Seismology. Physics and geology of earthquakes, causes, effects, distribution, seismic waves. (3 cr; prereq 1 and Phys 23T or #)

175. Principles of Gravity and Magnetic Exploration. Instruments, data reduction, interpretation. (2 cr; prereq Phys 23T)

176. Principles of Seismic Exploration. Seismic wave theory; reflection and refraction seismology. (3 cr, §176A; prereq Phys 23T)

176A. Principles of Refraction Seismic Exploration. Seismic wave theory; refraction seismology. (2 cr, §176; principally for civil engineering and geo-engineering students; prereq Phys 23T)

177. Principles of Electrical Exploration. Resistivity, electromagnetic, induced polarization, and other methods. (3 cr; prereq Phys 23T)

178. Stochastic Processes in Geophysics. Geophysical applications of linear system and random variable theory. (2 cr; prereq 176A and EE 108 or #; offered when demand warrants)

For Graduate Students Only

A. GENERAL GEOLOGY

200. Paleoecology

203. Advanced Invertebrate Paleontology

205. Research in Paleontology

206. Seminar: Paleontology

210. Research in Stratigraphy

211. Seminar: Stratigraphy

215. Research in Pleistocene Geology

216. Seminar: Pleistocene Geology

217. Research in Geomorphology

218. Seminar: Geomorphology

219. Seminar: Paleoecology

220. Geotectonics

221. Research in Structural Geology

222. Seminar: Structural Geology

B. MINERALOGY AND PETROLOGY

245. Research in Petrology

246. Seminar: Petrology

250. Research in Geochemistry

251. Seminar: Geochemistry

255. Advanced Mineral Deposits I

256. Advanced Mineral Deposits II

257. **Research in Mineral Deposits**
258. **Seminar: Mineral Deposits**
260. **X-Ray Crystallography**
261. **Research in Mineralogy and Crystallography**
262. **Seminar: Mineralogy and Crystallography**
264. **Seminar: Clay Mineralogy**

C. HYDROGEOLOGY

202. **Marine Geology**
213. **Organic Geochemistry**
214. **Seminar: Organic Geochemistry**
225. **Research in Sedimentology**
226. **Seminar: Sedimentology**
227. **Seminar: Limnology**
228. **Advanced Limnology**
229. **Research in Limnology**
230. **Methods for Analysis of Natural Waters**
231. **Research in Ground Water Geology**
232. **Seminar: Ground Water Geology**

D. GEOPHYSICS

270-271. **Theory of Elastic Wave Propagation I, II**

272. **Wave Propagation in Inelastic Media**
273. **Shock Wave Propagation in Solids**
274. **Earthquake Mechanisms**
275. **Seminar: Geophysics**
278. **Interpretation of Earthquake Seismograms**
279. **Geothermal Problems**
280. **Studies of the Crust and Upper Mantle**
282. **Research in Geophysics**

German (Ger)

(College of Liberal Arts)

Note — A student who has had high school German courses cannot register for an equivalent German course on an A-F basis without taking the German placement test. No placement test is required if he registers P-N.

1-2-3. Beginning German: Oral Approach. Experience in speaking and oral comprehension through the acquisition of basic speech patterns and knowledge of the structure of the German language. A reading knowledge is developed in the latter part of the course through reading and analyzing texts. (5 cr per qtr; lect on CCTV twice per wk, small drill sections 3 times per wk) C Wood

1A-2A-3A. Beginning German: Oral Approach. Basic experience in speaking, reading, and understanding German language and its structure through acquisition of basic patterns of speech and later through reading and analysis of texts. (5 cr per qtr)

1B-2B-3B. Beginning German: Language and Culture. Provides foundation for a reading knowledge adequate for cultural and professional purposes; a core of minimum essential vocabulary and familiarity with German structure necessary for speaking; an introduction to representative German figures such as Goethe, Heine, Thomas Mann, through a variety of German and English texts. (5 cr per qtr)

1Hf-2Hw. Honors Course: Beginning German. Covers material of 1B-2B-3B sequence. (5 cr per qtr, plus 5 cr on passing special exam after completing the 2 qtrs; for students of high ability as indicated by their college entrance records; prereq #; 5 class meetings per wk) Ramras

Horticultural Science (Hort)

(College of Agriculture, Forestry, and Home Economics)

21. Woody Plant Materials I. Trees, vines, and evergreens used in landscape planting, their identification, ecology, and landscape use. Lectures, laboratories, and field trips. (3 cr)

22. Woody Plant Materials II. Deciduous shrubs used in landscape planting, their identification, ecology, and landscape use. Lectures, laboratories, and field trips. (3 cr)

Mathematics (Math)

There are two sequences of courses in analytic geometry and calculus. They cover essentially the same material, but they are not identical. Math 21A-22A-23A and 31-32, 33 are specifically set up for students of engineering and the other curricula in the Institute of Technology. These courses are listed below with their descriptions.

The courses and sequences specifically set up for students in other colleges are listed below without descriptions. For description, see the *College of Liberal Arts Bulletin.*

Z. Preparatory Mathematics. (See *College of Liberal Arts Bulletin*)

T. Trigonometry. (See *College of Liberal Arts Bulletin*)

1-2-3. Mathematics. (See *College of Liberal Arts Bulletin*)

5A,B. Foundations of Arithmetic. (See *College of Liberal Arts Bulletin*)

8. Solid Geometry. (High School) Lines, planes, dihedral and polyhedral angles, polyhedrons, surfaces, prisms, cylinders, cones, prismatoids, and spheres. Three-dimensional visualization and sketching. Numerical exercises in areas, volumes, weights. (No cr; prereq plane geometry)

10. College Algebra and Analytic Geometry. (See *College of Liberal Arts Bulletin*)

10A. Algebra, Analytic Geometry and Elementary Functions. (See *College of Liberal Arts Bulletin*)

11. Intermediate Algebra. Fundamental operations, factoring, fractions, functions and graphs, linear equations, exponents and radicals, quadratic equations, ratio and variation, progressions, binomial theorem, logarithms. (No cr, §Z; prereq 1 yr high school algebra)

12. College Algebra and Trigonometry. Trigonometric functions, right triangles, oblique triangles, radian measure. Trigonometric formulas and identities, trigonometric curves, inverse trigonometric functions, trigonometric equations. Inequalities, theory of equations, determinants, mathematical induction, exponential and logarithmic functions, complex numbers. (No cr, §T and §15; prereq high school algebra or 11 or Z or equiv; 5 hrs per wk)

14A. Introduction to Computers. Introduction to Fortran II. General aspects of machine organization to provide a background for rules and restrictions. Concurrently, the general consideration of the structure of computational algorithms. Classical examples (Euclid's, etc.). Analysis of problems, construction of corresponding algorithms for solution, and translation into Fortran. Considerable emphasis on laboratory computations using Fortran programs. Applications coordinated with first course in mathematics. (2 cr, §30, §65; prereq 21A or ¶21A or 15 or ¶15; 2 lect or 1 lect and 2 lab hrs per wk)

14B-C. Computer Laboratory. Designed to coordinate with calculus and ordinary differential equations. An extension of Math 14A to cover Fortran IV. The applications, however, are at a more advanced level to include newly introduced concepts in the calculus. Numerical convergence compared to mathematical convergence. Introduction to elementary error theory. (1 cr per qtr; prereq 23A or ¶23A or 43 or ¶43 for 14B...32 or ¶32 or 55 or ¶55 for 14C; 1 lect and 2 lab hrs per wk)

15. College Algebra. (See *College of Liberal Arts Bulletin*)

15H. Honors Course: College Algebra. (See *College of Liberal Arts Bulletin*)

20. Mathematics of Investment. (See *College of Liberal Arts Bulletin*)

21A-22A-23A. Analysis I-II-III. Review of high school algebra; analytic geometry, calculus of functions of one variable, applications. (5 cr per qtr; primarily for IT students; prereq 12 or 4 yrs high school math including trigonometry)

21H-22H-23H. Calculus I-II-III. Same description and content as Math 21A-22A-23A. More emphasis on theory and basic concepts of calculus. (5 cr per qtr; prereq students will be selected from those eligible for Math 21A-22A-23A)

30. Fortran Survey and Orientation. Survey of basic Fortran language. Orientation in use of computer facilities. (1 cr; prereq 15 or 21A)

31-32. Calculus IV-V. Vector algebra, solid analytic geometry, elementary linear algebra, multidimensional differential and integral calculus, infinite series, elementary differential equations. (5 cr per qtr; prereq 23A)

33. Calculus VI. Vector calculus, continuation of multidimensional calculus and of infinite series. (5 cr; prereq 32)

31H-32H-33H. Honors Course: Calculus IV-V-VI. Same description and content as Math 31-32-33. More emphasis will be placed upon the theory and basic concepts. (5 cr per qtr; prereq ‡; 5 hrs per wk)

40. Calculus. (See *College of Liberal Arts Bulletin*)

40A. Introduction to Calculus of One and Several Variables. (See *College of Liberal Arts Bulletin*)

42-43-44. Analytic Geometry and Calculus I-II-III. (See *College of Liberal Arts Bulletin*)

42H-43H-44H. Honors Course: Analytic Geometry and Calculus I-II-III. (See *College of Liberal Arts Bulletin*)

55. Intermediate Calculus. (See *College of Liberal Arts Bulletin*)

60. Synthetic Metric Geometry. (See *College of Liberal Arts Bulletin*)

60A. Operational Methods for Linear Systems. (Primarily for EE students) Review of Fourier series and their applications to linear ordinary differential equations. The Fourier transform, mathematical properties, amplitude and phase spectra, energy. The Laplace transform, mathematical properties and elementary inversion techniques, applications to systems of ordinary differential equations, transfer function of a filter, time and frequency domain relations. (3 cr; prereq 32)

62. Introduction to the Theory of Equations. (See *College of Liberal Arts Bulletin*)

63. Linear Algebra. (See *College of Liberal Arts Bulletin*)

65. Introduction to Computer Programming. Basic Fortran computer language with extensions. Programming applications and techniques. The binary number system and elements of computer organization and machine language. Integral laboratory. Three lectures and nonscheduled laboratory. (4 cr; prereq 23A or 43)

66A-B. The Groups of Plane Geometry. Reflections. Transformation groups, homogeneous spaces. Circles. Metric geometry. Similitudes. Geometric inequalities. Circular transformations. Hyperbolic geometry. (3 cr per qtr, §60, §80C; prereq 43 or 23A)

70. Greek Mathematics. (See *College of Liberal Arts Bulletin*)

71. The Creation of Calculus. (See *College of Liberal Arts Bulletin*)

72. Topics in the History of Mathematics. (See *College of Liberal Arts Bulletin*)

75. Introductory Mathematics. Designed to prepare the sophomore mathematics major for the theoretical courses he will encounter during his junior and senior years. (3 cr; prereq 43 or 23A)

80A. Foundations of Arithmetic. (See *College of Liberal Arts Bulletin*)

80B. Foundation of Algebra. (See *College of Liberal Arts Bulletin*)

80C. Foundations of Geometry. (See *College of Liberal Arts Bulletin*)

99. Seminar: Mathematical Problems. Problems ranging from elementary algebra and geometry through undergraduate mathematics will be assigned and discussed weekly. (3 cr; prereq 32)

100A-B-C. Mathematics of Symbol Manipulation Systems. 100A: Finite automata theory: switching circuits, Boolean algebra and propositional logic. Kleene's theorem on regular sets. Algebraic aspects of finite automata: minimization, decomposition, synthesis. 100B: The computability of numerical functions: proofs for the basic results connecting abstract models of programmed digital computers, Turing machines, and general recursive functions. Normal form theorem. Universal machines. Unsolvability of halting problem. 100C: Symbol manipulation systems: the formal systems of Herbrand-Godel and Post. Post's normal form theorem. Formal grammars: introduction to the theory of Chomsky on context-free and other languages and related automata. Transduction of languages by automata. (3 cr per qtr; prereq 15 or 21A and 3rd yr standing or ‡)

101A-B-C. Nonnumeric and Systems Programming. The implementation of abstract theories of languages and compliers, Polish and Inverse-Polish notations. Techniques of string, stack, and file manipulation. Applications of heuristic programming. Aspects of nonnumeric computer programming including information retrieval, artificial intelligence, and simple game theory. Systems programming, monitors, executive programs. Integration of hardware and software systems. (3 cr per qtr; prereq 166)

104. Variational Problems in Engineering. Euler-Lagrange equations, isoperimetric problems, geodesics, Fermat's and Hamilton's principles, vibration and stresses in elastic bodies, methods of Rayleigh-Ritz, Galerkin, Kantorovich, etc., eigenvalues and eigenfunctions. (3 cr; prereq 107B or 148 or 150 or ‡)

106. Differential Equations. (See *College of Liberal Arts Bulletin*)

107A-B-C. Advanced Calculus. 107A: Differentiation of functions of several variables; vector algebra; curves in three dimensions; directional derivative and gradient; inverse transformation and implicit function theorems; change of variables in multiple integrals. 107B: Line and surface integrals; Stokes' theorem; convergence of infinite series; orthogonal functions; uniform convergence; integration and differentiation of series. 107C: Real numbers; continuous functions; limits; properties of continuous functions; differentiation; the Riemann integral; improper integrals. (3 cr per qtr; prereq 32 or 55 for 107A, 107A for 107B, 107B or ‡ for 107C)

109s. Theory of Numbers. Elementary properties of integers; prime and composite numbers; Euclid's algorithm; congruences; the theorems of Fermat and Wilson; primitive roots; indices; Diophantine equations. (3 cr; prereq 31 or 44)

110f,w,s. Tutorial Course in Advanced Mathematics. Qualified students whose needs are not met by courses offered may make special arrangements for obtaining the content of other graduate courses regularly offered by the department. (Cr ar; prereq 32 or 55)

111. Development of the Number System. Systematic construction of the real number system by extension from the natural numbers via rational numbers to irrational numbers; negative numbers; properties of the system; operation with numbers and laws governing the operations. (3 cr, §111A, B; prereq 31 or 44)

111Aw-Bs. The Development of the Number System. Systematic construction of the real number system by extension from the natural numbers via rational numbers to irrational numbers; negative numbers; properties of the system; operations with numbers and laws governing the operations. (3 cr per qtr; prereq 31 or 44)

112f. Elementary Set Theory. Basic properties of operations on sets, cardinal numbers, simply ordered sets, well-ordered sets, ordinal numbers, axiom of choice, axiomatics. (3 cr; prereq 31 or 44)

112A-B-C. Mathematical Logic. Propositional and predicate calculi, models for systems of logic, recursive functions, decision and completeness problems. (3 cr per qtr; prereq 32 or 55 or Phil 155 or ‡)

115A. Differential Geometry. Plane and space curves, Frenet formulas, elementary theory of surfaces. May be followed by 115B (and 115C) to satisfy a 2- (3-) quarter sequence requirement. (3 cr; prereq 147 or 33 or 107B)

115B-C. Differential Geometry. Introduction to differential forms. Advanced theory of surfaces, integral geometry, Riemannian geometry. (3 cr per qtr; prereq 115A and knowledge of linear algebra)

117A-B-C.‡ Geometry. Selected chapters of geometry, such as convex bodies, projective geometry, geometry and imagination, elementary algebraic geometry, geometry of transformation groups, axiomatic geometry, geometrical constructions. (3 cr per qtr; prereq 31 or 44 for each qtr)

119. Topics in Finite Groups. An introduction to the theory of finite groups. Group axioms, examples of groups, subgroups and direct products, factor groups and composition series, permutation groups, prime power groups, Abelian groups. (3 cr; prereq 31 or 44)

120. Group Representations. Elementary theory of finite groups and of infinite Abelian groups with some application to permutation and crystallographic groups; representation by matrices, characters. (3 cr; prereq 131A)

125A-B. Critical Reasoning in Mathematical Analysis. The subject matter of this course, based on the elementary concepts of mathematical analysis, is used mainly as a vehicle for the principal aim of the course: to develop in the student an understanding of mathematical rigor. (3 cr per qtr, §130A-B-C; prereq 31 or 44)

127-128-129. Applied Mathematics for Social and Biological Sciences. Mathematical tools and concepts other than statistics useful in the behavioral sciences. Examples and problems taken from the fields concerned. Topics include matrices, functions of several variables, probability, difference equations, learning models, two-person games. (3 cr per qtr; not acceptable for mathematics majors [all degrees] as part of their mathematics programs; prereq 32 or 55)

130A-B-C. Introduction to Analysis. Theory of real numbers; elements of point set theory; limits; continuity; infinite sequences and series; integration and differentiation; vector analysis. (3 cr per qtr; principally designed for students planning to take grad work with a major in mathematics, as preparation for grad courses in analysis; prereq 32 or 55)

Stat 131-132-133. Theory of Statistics. 131: Probability models, univariate and bivariate distributions, independence, basic limit theorems. 132-133: Statistical decision theory, sampling, estimation, testing hypotheses, parametric and nonparametric procedures for one-sample and two-sample problems, regression, analysis of variance. (3 cr per qtr; prereq ¶Math 55 for 131, ¶107A-B for 132-133, or equiv)

131A-B-C. Fundamental Structures of Algebra. A theory-oriented course, principally designed for students planning graduate work with a major in mathematics. Group theory — including topics such as normal subgroups, homomorphism, automorphisms and the Theorems of Lagrange, Cayley and Sylow. Ring theory — rings, integral domains, Euclidian rings, polynomial rings, fields. Linear algebra — abstract approach to vector spaces, linear transformations, and the theory of canonical forms including the Jordan and rational canonical forms. (3 cr per qtr, §142-143...§180 for 131A; prereq 31 or 44)

133B-134B. Probability with Technological Applications. Spectral analysis of stationary processes, linear and nonlinear transformations, prediction and smoothing, recurrent events, random walk and diffusion, Markov chains, Poisson processes. (3 cr per qtr; prereq Stat 131 and ‡)

135. Integral Equations. Introduction to integral equations with emphasis on applications and techniques of solution including the 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. (3 cr; prereq 32 or 106)

140. Projective Geometry. Geometric properties invariant under projective transformation; theorems of Desargues, Pascal, and Brianchon, and applications. Methods used in some quarters are mainly synthetic; in other quarters they are mainly analytic. (3 cr; prereq 32 or 44)

142-143. Matrix Theory with Applications. Systems of linear equations, determinants, finite dimensional vector spaces, matrices, characteristic values and their numerical estimation, reduction to canonical forms, quadratic and bilinear forms. Applications. (3 cr per qtr, §149, §131B-C; prereq 31 or 44)

144-145-146. Fourier Series and Orthogonal Functions. General theory of orthonormal functions developed and applied to Fourier, Legendre, Bessel, Hermite, and other series. Convergence and summability theorems are proved, and Fourier integral is considered. (3 cr per qtr; prereq 107A-B or ‡)

147. Vector Analysis. Scalar and vector products, derivatives, geometry of space curves, del operator, line and surface integrals, divergence and Stokes' theorem, transformation of coordinates, dyadics, applications. Mostly a technique course, intended mainly for students whose interests are not theoretical but who wish to learn the relevant mathematical facts and methods. (3 cr, §33; prereq 32 or 55)

148. Differential Equations. Linear differential and difference equations with constant coefficients, isoclines, phase plane, reduction in order, Picard's method, uniform convergence, series solutions, Bessel functions, Legendre polynomials, introduction to boundary value problems. Mostly a technique course, intended mainly for students whose interests are not theoretical but who wish to learn the relevant mathematical facts and methods. (3 cr, §150; prereq 32 or 106)

149. Determinants and Matrices. Determinants, matrices, linear equations, vector spaces, quadratic and bilinear forms, characteristic roots, applications to systems of ordinary differential equations. Mostly a technique course, intended mainly for students whose interests are not theoretical but who wish to learn the relevant mathematical facts and methods. (3 cr, §63, §131B, §142; prereq 32 or 55)

150. Theory of Ordinary Differential Equations. Linear equations of second order, successive approximations. Existence theorems, systems of ordinary differential equations. Numerical integration and solution by series. (3 cr, §148; prereq 32 or 106)

155-156. Tensor Analysis with Applications. (3 cr per qtr; prereq vector analysis, 1 qtr linear algebra, or ‡)

157-158-159. Methods of Applied Mathematics. Integrated study of analytic tools used in applications of mathematics; emphasis on technique. Real and complex variables, matrices, ordinary and partial differential equations, calculus of variations, asymptotic expansions, etc. (3 cr per qtr; prereq 107C or 130C or ‡)

161-162-163. Analytical Dynamics. Basic laws and principles. Lagrange's equations. Motion of particles and rigid bodies; e.g., satellites and gyroscopes. Matrix methods for small oscillations. Variational methods, Hamilton's principle, extremal properties of eigenvalues. Hamilton's equations, transformation theory, separable systems. (3 cr per qtr; prereq vector analysis, 1 qtr linear algebra)

164. Theory of Programming Modern Digital Computers. Number systems. Complement arithmetic. Logical organization of a computer. Basic and advanced absolute machine language programming. Arithmetic operations. Scaling. Introduction to symbolic programming. (3 cr; prereq 32 or 55 or ‡)

165. Theory of Programming Modern Digital Computers. Logical operations. Bit and character manipulation. Assembly programs. Symbolic assembly programming. Interpretive languages. Simulators. Libraries. Application. Input-output. Fortran and mixed language programming. (3 cr; prereq 164)

166. Theory of Programming Modern Digital Computers. Boolean algebra and logical circuitry of computers. Logical theory of digital machine arithmetic. Introduction to Algol, List processing. Compilers and their structure. Basic ideas of compiler implementation. (3 cr; prereq 164, 165)

167. Fourier Series and Boundary Value Problems. 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. (3 cr, §173; prereq 32 or 106)

168A. Elementary Theory of Complex Variables. Derivative and integral of a function of a complex variable. Cauchy's integral theorem and formula, residues. Application to evaluation of integrals, conformal mapping. (3 cr; prereq 107B, or 147, 148, 149)

168B. Applications of Complex Variables. Conformal mapping, Schwarz-Christoffel transformations, Laplace transforms, and applications. (3 cr; prereq 168A or ‡)

169. Mathematical Theory of Fluid Flow. The general equations of fluid mechanics. Concepts from thermodynamics. The classical constitutive equations. Specialization to various subfields of fluid mechanics, including hydrostatics, barotropic perfect fluids, gas dynamics and viscous flow theory. Examples of exact solutions. (3 cr; prereq 147, 174, or 147, 168A, or ‡)

173-174-175. Elementary Partial Differential Equations. Partial differential equations of theoretical physics, one-dimensional wave equation, characteristics, classification of second order equations, heat and Laplace equations, uniqueness, maximum principle, orthogonal systems, Fourier series, separation of variables. Complex numbers, derivatives and integrals of analytic functions, elementary functions and their geometry, Cauchy's integral theorem and formula, Laurent expansions, evaluation of contour integrals by residues. Fourier and Laplace transforms and their inversion, method of residues, applications to ordinary and partial differential equations, applications to the heat, wave, and Laplace equations. (3 cr per qtr, §167, §168A; prereq 32, 55 or 106 or ‡)

178. Probability. Elementary principles of probability, total and compound probability, expectation, repeated trials, and as time permits topics chosen from the following: Stirling's formula, the probability integral, geometrical probability, probability of causes, Bayes's theorem, errors of observation, principle of least squares. (3 cr; prereq 31 or 44)

178A-B-C. Introduction to Probability. Logical development and various applications of probability. Probability spaces, random variables, central limit theorem; Markov chains. (3 cr per qtr; prereq 107B or Stat 133 or ‡)

179. The Lebesgue Integral. Definition. Basic limit theorems. Comparison with Riemann integral. Lebesgue measure. Absolute continuity. (3 cr; prereq 107B or 130B or ‡)

180. Group Theory. Permutation groups; groups related to geometrical configuration; invariant subgroups, the Jordan-Hölder composition theorem, Sylow groups, Abelian groups, elementary divisors, representation theory, applications. (3 cr; prereq 143 or ‡)

181-182-183. Selected Topics in the Theory of Numbers. (3 cr per qtr; prereq 107B or 130B or ‡)

181A-B. Introduction to Topology. Metric spaces: completeness, compactness, uniform continuity. Abstract topologies: comparison of topologies, separation axioms, homeomorphisms. Product and function spaces. Connectedness. Local connectedness, Hahn-Mazurkiewicz Theorem, characterization of arc, Jordan curve theorem. Introduction to algebraic topology. (3 cr per qtr; prereq 32 or 55)

184. Elementary Numerical Analysis in Engineering. Finite differences, interpolation, summation of series, numerical integration, Euler-MacLaurin formula and asymptotic expansions. Numerical solutions of systems of algebraic and transcendental equations. Newton's and Graeffe's method. (3 cr; prereq 32 or 106)

185-186. Numerical Analysis in Engineering. Approximation of functions and least squares. Approximate solution of ordinary and partial differential equations, Moulton's, Runge's, relaxation and iteration methods. Calculation of eigenvalues of matrices and differential problems, Rayleigh-Ritz method. Integral equations. Programming of computers. (3 cr per qtr; prereq 184 or ‡)

187. Non-Euclidean Geometry. Foundations of Euclidean geometry, Euclid's fifth postulate and its implications. Hyperbolic plane geometry and trigonometry. Elliptic plane geometry and trigonometry. Consistency of non-Euclidean geometry. (3 cr; prereq 31 or 44)

188. Topics in Topology. For the undergraduate and beginning graduate student who has not had a course in topology. It contains an axiomatic approach to topics from the fundamentals of general topology that are basic to modern analysis. Topics to be discussed are taken from the following: elementary set theory, topologies and topological spaces, mappings of topological spaces, connected spaces, compact spaces, homeomorphisms, metric spaces, convergence, and special types of topological spaces such as regular spaces and normal spaces. (3 cr; prereq 31 or 44; 3 hrs per wk)

190A-B-C. General and Algebraic Topology. General topological and metric spaces. Function spaces. Fundamental group and covering spaces. Singular and simplicial homology theory. Betti and torsion groups. Fixed point theorems and applications to analysis. Classification of surfaces. (3 cr per qtr; prereq 131A or ¶131A)

192. Theory of Approximation in Numerical Analysis. Orthogonal functions, Chebyshev approximations, rational approximations, approximations in several variables, use of approximation in computing. (3 cr; prereq 168A or 175, 185, or ‡)

196-197-198. Special Functions in Mathematical Analysis. Asymptotic expansions. Gamma and beta functions. Hypergeometric functions as solutions of differential equations. Bessel functions using Sommerfeld's contour integrals. Legendre functions. (3 cr per qtr; prereq 168A or 175 or ‡)

199A, B, C. Problem Course. Develops problem-solving techniques in many areas of mathematics. Topics range from elementary to advanced levels, adapted to students of varied backgrounds. (3 cr per qtr; prereq ‡)

For Graduate Students Only

200A-B-C. Recursion Theory

201A-B-C. Axiomatic Set Theory

202A-B-C. Advanced Logic

203A-B-C. Topics in Logic

204A-B-C. Model Theory

205A-B-C. General Algebra

206A-B-C-D-E. Topics in Algebra

207A-B-C. Foundations of Algebra

208A-B-C. Structure of Rings and Algebras

209A-B-C. Group Theory

210A-B-C. Theory of Local Rings

211A-B-C. Homological Algebra

212A-B, C. Topics in Number Theory and Algebraic Geometry

221A-B-C. Complex Analysis

222A-B-C. Real Analysis

223. Theory of Differentiation

223A-B-C. Topics in Real Analysis

225A-B-C. Asymptotic Methods in Linear Analysis

226A-B-C. Conformal Mapping

227A-B-C. Riemann Surfaces

228A-B-C. Topics in the Theory of Analytic Functions

229. Quasiconformal Functions

229A-B, C. Theory of Quasiconformal Mapping

230A-B-C. Topics in Several Complex Variables

231A-B-C. Dirichlet Series

232A-B-C. Nonlinear Functional Analysis and Its Application

233A-B-C. Topological Dynamics

234A-B-C. Ergodic Theory

235A-B-C. Functional Analysis

236A-B-C. Linear Spaces and Operator Theory

237A-B-C. Topics in Operator Theory

238A-B-C. Banach Algebras and Harmonic Analysis

239A-B-C. Generalized Functions, Distributions and Applications

240A-B-C. The Wiener and Feynman Integrals

241A-B-C. Topological Groups

242A-B-C. Group Representations

243A-B-C. Abstract Operator Theory

246A-B-C. Topics in Point Set Topology

247A-B-C. Algebraic Topology

248A-B-C. Homotopy Theory

249A-B-C. Convex Sets

250A-B-C. Riemannian Geometry

251A-B-C. Differential Topology

252A-B-C. Lie Groups and Lie Algebras

253A-B-C. Topics in Advanced Differential Geometry

254A-B-C. Algebraic Geometry

260A-B-C. Theory of Probability

261A-B-C. Stochastic Processes

262A-B-C. Topics in the Theory of Probability

263A-B-C. Stochastic Control Theory

266A-B-C. Theory of Ordinary Differential Equations

267A-B-C. Theory of Nonlinear Oscillations

268A-B-C. Topics in Differential and Difference Equations

271A-B-C. Partial Differential and Integral Equations of Applied Mathematics

272A-B-C. Theory of Partial Differential Equations

273A-B-C. Topics in Partial Differential Equations

275A-B-C. Calculus of Variations in the Large

276A-B-C. Calculus of Variations and Minimal Surfaces

277A-B-C. Potential Theory

280A-B-C. Mathematics of Computers and Control Devices

282. Advanced Numerical Analysis of Linear Systems

283. Advanced Numerical Analysis of Partial Differential Equations

284A-B-C. System Programming

285A-B-C. Formal Languages and Automata

286A-B-C. Advanced Methods of Applied Mathematics

287. Variational Methods in Boundary Value Problems

288. Variational Methods in Eigenvalue Problems

289A-B-C. Mathematical Theory of Elasticity

290A-B-C. Mathematical Theory of Fluid Dynamics

291. Mathematical Aspects of Boundary Layer Theory

292A-B-C. Joint Seminar with Aeronautical Engineering

293. Information Theory

296A-B-C. Mathematical Problems in Theoretical Physics

297. Selected Topics of Celestial Mechanics

298A-B. Topics in Control Theory

299A-B-C. Reading and Research

School of Mechanical and Aerospace Engineering

Engineering Graphics (EG)

1. **The Slide Rule.** Computation practice and theory. Design of special scales. (1 cr [0 cr for students registered in IT]; prereq higher algebra and trigonometry or ‡; 1 rec hr per wk)

25. **Engineering Graphics.** Engineering representation and analysis of systems of projection; the coordinate system, graphical solution of space problems, intersections and developments. Precision in graphics and techniques of sketching; pictorial projection systems, size description, standard and simplified practices applied to graphic communication. (4 cr; prereq ¶Math 21A or ‡; 3 lect, 1 rec, and open lab hrs per wk)

26. **Graphical Computation.** Graphical computation of engineering problems involving algebra, calculus, and statics. Functional scales, nomography, representation and analysis of empirical data. (2 cr; prereq Math 22A; 2 lect and open lab hrs per wk)

27. **Graphical Communication and Analysis.** Engineering representation and analysis. Single and multiview systems, specification and control of size. Graphical summation and resolution of 2- and 3-space vectors. (2 cr; prereq 25; 2 lect and open lab hrs per wk)

101. **Illustration for Design.** Graphical approach relating functional design to space requirements and aesthetic considerations. Orthographic and pictorial presentation of information. Principles of shading, sketching. (3 cr; prereq 27 or ‡; 2 lect hrs per wk; lab ar)

118. **Graphic Analysis of Experimental Data.** Derivation of empirical equations correlating graphic and algebraic methods. (3 cr; prereq 26, Math 23A or ‡; 3 lect hrs per wk)

120. **Advanced Descriptive Geometry.** Graphic solutions involving one-view drawings; intersection, tangency, and clearance determinations of curves and of warped surfaces. (3 cr; prereq 27, Math 22A or ‡; 3 lect hrs per wk)

130. **Nomography.** Application of geometry to the development of alignment charts. Parallel and nonparallel straight line scale and curved scale nomograms; transverse, concurrent, proportionality and combined charts. (3 cr; prereq 26, Math 22A or ‡; 3 lect hrs per wk)

131. **Graphical Mathematics.** Graphical approach to problems involving algebra, differential and integral calculus; use of straight and curved line networks and

combinations of networks. Correlation of algebraic and descriptive geometry solutions particularly relating to numerical control of automatic machines. (3 cr; prereq 26, Math 23A or ‡; 3 lect hrs per wk)

194. **Graphics in Engineering Problems.** A synthesis and extension of the procedures of graphical mathematics, nomography and descriptive geometry in the solutions of complex problems within the individual student's area of interest. (2-4 cr; prereq 130 or 131 or ‡; hrs ar)

Industrial Engineering (IE)

100. **Introduction to Industrial Engineering Analysis.** Management and decision-making, analytical methods in production management, design of production systems, operation and control of production systems. (3 cr; prereq ME 99 or ‡; 3 lect hrs per wk)

110. **Introduction to Work Analysis.** 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, line balancing. (4 cr; prereq 100 and ME 99; 3 lect and 1 lab hrs per wk)

120. **Probability Models in Industrial Engineering and Operations Research.** Concepts of compound statements, sets and functions, conditional probabilities and simple stochastic processes (including finite Markov chains) and their relation to selected problems in industrial engineering and operations research. Waiting line models, renewal and replacement models, dynamic programming, Markov processes with rewards; Monte Carlo methods. (3 cr; prereq ME 99 or equiv; 3 lect hrs per wk)

130. **Introduction to Operations Research.** Industrial applications of operations research techniques using linear programming, decision models, game theory and general optimization techniques; industrial problems in allocation, inventory control, competitive strategies, scheduling. (4 cr; prereq ME 99 or equiv)

133A-134A. **Mathematical Methods in Operations Analysis.** Linear programming, simplex technique, network flows, finite games, birth-death processes; applications to allocation, scheduling, transportation, waiting lines, inventory, reliability. (3 cr per qtr; prereq ME 99 or Stat 90 or 131 or ‡; 3 rec hrs per wk)

140. **Analysis of Production Processes.** A case course of problems in production engineering and production management. Analysis of production problems from selected industries. Emphasis is placed on developing the student's ability to recognize and diagnose industrial problems. (3 cr; prereq 172; 3 lect hrs per wk)

141. **Industrial Metrology.** Fundamental concepts of the science of industrial measurements. Variability of manufacturing process, process capability, errors of measurement. (3 cr; prereq ME 99 and 170; 2 lect and 3 lab hrs per wk)

145. **Manufacturing Process Planning.** Concepts and techniques of planning optimum manufacturing processes. Principles of product design that result in economical production are emphasized. Analysis of part drawings to determine the nature and sequence of production processes. (3 cr; prereq ME 170; 3 lect hrs per wk)

154. Advanced Methods Engineering and Work Measurement. Multiple operation analysis, advanced work measurement techniques, incentives. (3 cr; prereq 110; 2 rec and 3 lab hrs per wk)

155. Industrial Wage Administration. Job evaluation, wage surveys, wage policies, establishment and administration of incentive wage plans. (3 cr; prereq 110; 3 lect hrs per wk)

165. Industrial Plants. Analysis of materials flow; layout of production and service departments; plant buildings, service facilities, and handling equipment. (3 cr; prereq 110; 2 rec and 3 lab hrs per wk)

167. Materials Handling. Development of materials handling systems and selection of equipment; industrial packaging techniques. (3 cr; prereq 110; 3 rec hrs per wk)

170. Production Planning and Control. Planning of production requirements; routing, scheduling, and coordination of production; inventory policies and control. (3 cr; prereq 100; 3 rec hrs per wk)

171. Quality Control. Quality standards, application of statistical methods and sampling theory; interpretation of results and corrective action. (3 cr; prereq Stat 90 or ME 99 or equiv or ‡; 3 rec hrs per wk)

172. Manufacturing Cost Analysis. Financial accounting concepts, standard cost systems, manufacturing cost accounting, cost information for management decision-making. (3 cr; prereq 100; 3 lect hrs per wk)

173. Engineering Economic Analysis. Analysis of capital expenditures and annual operating costs as the basis for management policies and decisions. (3 cr; prereq 100; 3 rec hrs per wk)

175. Elements of Reliability. Principles of experimentation, systems design, measurement, simulation, and field data utilization necessary for a total approach to producing a reliable product. (3 cr; prereq Stat 90 or ME 99; 3 lect hrs per wk)

177. Industrial Sampling Techniques. Selection and operation of attributes sampling plans; operating characteristic curves; sampling techniques for continuous production; variables sampling plans; administrative and economic comparisons. (3 cr; prereq 171; 3 lect hrs per wk)

180. Management for Engineers. Management functions and relations with employees, other supervisors, and staff departments. (3 cr; prereq 100; 3 rec hrs per wk)

182. Industrial Safety. Safety requirements for production processes, equipment, and plants; organization and administration of safety programs. (3 cr; prereq 100; 3 rec hrs per wk)

193. Introduction to Optimal Control and Dynamic Programming. Concepts of optimization, linear and nonlinear optimal systems, adaptive systems, stochastic optimization problems and introduction to dynamic programming. (3 cr; prereq ME 199; 3 lect hrs per wk)

194. Topics in Management Science. Analytical tools for decision-making and management of the production function. Emphasis upon topics appearing in the current literature; mathematical models, assumptions, limitations, and new developments. (3 cr; prereq 15 cr in industrial engineering; 3 lect hrs per wk)

195-196. Applied Industrial Engineering. Industrial engineering surveys and programs; case problems; studies in local plants. (3 cr per qtr; prereq 15 cr in industrial engineering; hrs ar)

198. Design and Analysis of Experiments I. One-factor experiments, design constructed to reduce the experimental error, general linear regression model, the analysis of variance, estimation and comparison of effect, orthogonal contrasts, components of variance, fixed random, and mixed models, incomplete block designs, introduction to general factorial experiments. (3 cr; prereq ME 99 or equiv or ‡; 3 lect hrs per wk)

199. Design and Analysis of Experiments II. Two or more factor experiments, designs involving crossed, nested, and mixed classifications; qualitative and quantitative factors; experiments, block confounding, fractional factorial experiments, introduction to response surface analysis. (3 cr; prereq 198 or ‡; 3 lect hrs per wk)

For Graduate Students Only

251-252-253.‡ Advanced Industrial Engineering

261-262-263.‡ Production Engineering Problems

271-272-273.‡ Industrial Engineering Research

Mechanical Engineering (ME)

22. Analysis of Mechanism Systems. Kinetic analysis of mechanisms based upon constraint equations and Newtonian mechanics. Degrees of freedom of rigid body mechanisms. Geometric synthesis with three and four accuracy points. (4 cr; prereq MM 36; 3 lect and 2 lab hrs per wk)

23. Mechanical Engineering Systems Analysis. Determination of response of engineering systems utilizing transfer function representation. Analogies between engineering systems based upon transfer function equivalence. (4 cr; prereq 22; 3 lect and 2 lab hrs per wk)

24. Optimum Design of Mechanical Elements. Application of fundamental principles to the design of typical mechanical components. Engineering approach to the analysis and synthesis of machines. Optimum design criteria. (3 cr; prereq 23 or ¶23, MM 37; 2 lect and 3 lab hrs per wk)

30. Thermodynamics. Properties, equations of state, and processes of engineering thermodynamic systems and devices. Application of fundamental laws correllating energy with heat, work, and mass transfer. Equilibrium and irreversibility. (3 cr; open to EE majors; prereq Math 32 or ¶Math 32, Phys 23; 3 lect hrs per wk)

30A-31A. Thermodynamics. Properties, equations of state, and processes of thermodynamic systems and devices. Application of first and second laws correlating energy with heat, work, and mass transfer. Equilibrium and irreversibility. (4 cr per qtr; prereq Phys 23, Math 32; 4 lect hrs per wk)

33-34-35. Measurements Laboratory I, II, III. 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. (2 cr per qtr; prereq Math 32 for 33, 30A or ¶30A for 34, 34 for 35; 1 lect and 3 lab hrs per wk)

90-91-92-93. Industrial Assignment. Engineering intern curriculum, industry laboratory quarters (work periods). Grades are based on a formal written report by the student, covering his work during the industrial assignment. (2 cr per qtr; prereq regis in engineering intern program)

99. Introduction to Engineering Analysis. Principles of measurement, concept of uncertainty and variability, models in engineering analysis, decision methods, estimation methods, introduction to design of experiments. (3 cr; prereq Math 23A or ♯; 3 rec hrs per wk)

101-102. Summer Employment I, II. (2 cr per qtr; prereq completion of 2nd yr work and Δ; fall qtr only)

110. Control of Metal Working Processes. Inspection by x-ray, gamma-ray, magnetic particle, metallographic, and chemical methods. (3 cr; prereq 170; 1 lect and 6 lab hrs per wk)

111. Advanced Casting Processes. Advanced techniques and new developments in molding and casting; foundry control procedures. (3 cr; prereq 110; 2 lect and 3 lab hrs per wk)

112. Properties and Fabrication of Plastics. Materials, equipment, and processes for fabrication of plastics. Plastic product and mold design. (3 cr; prereq 170 or ♯; 2 lect and 3 lab hrs per wk)

113. Advanced Metal Cutting. Advanced machine tool operation. Selection, tooling, and set-up of machine tools for production. (3 cr; prereq 170; 1 lect and 6 lab hrs per wk)

114. Advanced Welding. Theory and applications of welding processes; factors affecting weldability; conisderations in the design of weldments. (3 cr; prereq 170; 2 lect and 3 lab hrs per wk)

122. Advanced Analysis and Synthesis of Mechanism Systems. Kinematic and dynamic analysis of mechanism systems, gears and cams. Synthesis of mechanism systems, function generation, coupler curves and computerized design of mechanism systems. (3 cr; prereq 23; 3 lect hrs per wk)

123. Creative Engineering. Application of fundamentals of engineering design with emphasis on creative aspects. (3 cr; prereq 4th-yr engr; 1 lect and 6 lab hrs per wk)

124. Experimental Stress Analysis. Experimental application and theoretical evaluation of the methods of stress analysis. Strain gauges, surface coatings, photoelasticity, dynamic stress measurements, penetration methods, and fracture methods. (3 cr; prereq MM 37; 2 lect and 3 lab hrs per wk)

125. Machine Design Laboratory. Use of vibration instruments, stroboscopes, sound meters and analyzers, photoelastic, polariscope, electronic measuring devices and testing machines. (2 cr; prereq 23; 1 lect and 3 lab hrs per wk)

127. Friction and Lubrication. Friction mechanism and boundary lubrication. Hydrodynamic and hydrostatic lubrication theory applied to finite bearings. Introduction to gas bearings. (3 cr; prereq CE 101A or equiv; 3 rec hrs per wk)

128. Photoelastic Stress Analysis. Fundamentals of advanced stress analysis. Theory of photoelasticity and operation of polariscopes. Applications to solutions of special design problems. (3 cr; prereq MM 37; 2 lect and 3 lab hrs per wk)

129. Vibration Engineering. Advanced vibration theory with application to vibration absorption, and isolation. (3 cr; prereq 23; 3 lect hrs per wk)

133. Heat Transmission. Introduction to conduction, convection, and radiation of heat and their utilization in engineering applications. Heat exchangers. (3 cr; prereq 30A and CE 101A or Aero 100A or ‡; 3 lect or rec hrs per wk)

134. Thermodynamics of Fluid Flow. Thermodynamic analysis of internal flow of viscous and compressible fluids. Applications to various flow processes and components in engineering systems. (3 cr; prereq 31A, CE 101A or equiv; 3 rec hrs per wk)

136. Reactor Heat Transfer. Heat conduction with internal heat generation, thermal stresses, liquid metal heat transfer, forced convection in noncircular ducts, boiling and two-phase flow. (3 cr; prereq 133 or equiv; 3 rec hrs per wk)

137A. Thermodynamics of High Temperature Gases. Energy exchange processes in high temperature gases; determination of composition and properties of such systems. Thermal equilibrium. Quasi-neutrality. (3 cr; prereq 133; 3 lect hrs per wk)

137B. Thermodynamics of High Temperature Gases. Generation of gaseous high density plasmas. Diagnostic methods with emphasis on plasma spectroscopy and enthalpy probes. Plasma heat transfer. (3 cr; prereq 137A or ‡; 3 lect hrs per wk)

137C. Thermodynamics of High Temperature Gases. Arc gas heaters, plasma welding, spraying, and cutting, plasma wind tunnel and reentry simulation, plasma propulsion, MHD energy conversion. (3 cr; prereq 137A and B or ‡; 3 lect hrs per wk)

140-141. Thermodynamics of Modern Power Devices. Study of modern power devices including gas and solid state thermocouple, magnetohydrodynamic systems, fuel cells, and solar energy systems. Emphasis is placed on the thermodynamic principles and transport phenomena involved in each device. (3 cr per qtr; prereq 133; 3 rec hrs per wk)

142. Vapor Cycle Power Systems. Vapor cycle analysis, regeneration, reheat, compound cycle modifications, combined gas turbine-vapor cycle systems, binary systems. Combustion problems; solar, nuclear, and unusual energy sources for space power systems. (3 cr; prereq 31A; 3 rec hrs per wk)

143. Turbomachinery. Theoretical analysis of energy transfer between fluid and rotor, principles of axial, mixed, and radial flow compressors and turbines. Applications to gas turbines, fluid transmissions and power plants. (3 cr; prereq 31A; 3 rec hrs per wk)

146A. An Introduction to Combustion and Propulsion. Flame propagation, quenching and ignition in a gaseous mixture; combustion of solid and liquid particles, and gaseous jets. Principles of propulsion, thrust, specific impulse and exhaust velocity. (4 cr; prereq 133 or ¶133; 4 rec hrs per wk)

148-149. Chemistry of Combustion. The nature of combustion problems. Ignition, propagation, quenching, and burning limits. Thermochemistry and the use of the partition function in calculating thermodynamic properties, free energy, and equilibrium constants. Chemical kinetics and the steady state approximation applied to combustion phenomena. (3 cr per qtr; prereq 146A or ¶146A or ‡; 3 lect hrs per wk)

150. Internal Combustion Engines. Principles of spark ignition engine, fuel-air cycle analysis, combustion flames, knock phenomena, air flow and volumetric efficiency, mixture requirements, ignition requirements and performance. (3 cr; prereq 31A or ¶31A; 3 rec hrs per wk)

151. Advanced Internal Combustion Engines. Principles of the diesel engine, combustion of stratified charge, knock, theory of spray formation and vaporization. Fuels and deposits, engine lubrication, air and liquid cooling. (3 cr; prereq 150; 3 rec hrs per wk)

152. Gas Turbines and Compound Engines. Gas turbine cycles, regeneration, reheat, and intercooling. Free turbine and free piston gasifier. Scavenging of two-stroke engines, matching of compressor and turbine to engine. Turbo-jet engine performance. (3 cr; prereq 31A; 3 rec hrs per wk)

155. Rocket Propulsion. 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. (3 cr; prereq 146A or ¶146A or ‡; 3 rec hrs per wk)

159. Power and Propulsion Laboratory. Quarterly group student projects relating to performance of power and propulsion system components. Performance of engines, turbines, and rockets. Combustion, fluid flow, and heat transfer problems in power systems. (2 cr; prereq 34, 31A; 1 lect and 3 lab hrs per wk)

160A. Thermal Environmental Engineering. Mechanical vapor compression refrigeration cycles; thermodynamic properties of moist air; h-w diagram for moist air; solar radiation; steady-state and periodic heat transmission in structures; water vapor transmission in structures; effects of thermal environments upon people, processes, and materials; thermal loads; thermal environmental control systems. (4 cr; prereq 133; 4 lect hrs per wk)

164. Refrigeration and Cryogenics. Low temperature mechanical vapor compression cycles, thermodynamics of binary mixtures; the h-x diagram, absorption refrigeration; thermoelectric cooling; gaseous air cycle; steam-jet refrigeration. Liquefaction of air, hydrogen, and helium; production of oxygen and nitrogen by separation of air; other cryogenic topics. (3 cr; prereq 160A; 3 lect hrs per wk)

166. Industrial Ventilation and Exhaust System. Contaminants, dispersion mechanisms, fans, injectors, natural drafts, and control velocities as applied to manufacturing and processing systems. (3 cr; prereq 160A; 3 lect hrs per wk)

169. Psychrometrics and Air Conditioning Laboratory. Psychrometry and humidity measurement; experimental studies on refrigeration systems and on the processing of moist air. (2 cr; prereq 34, 160A; 1 lect and 3 lab hrs per wk)

170. Manufacturing Processes. Analysis and description of the physical and economic principles underlying manufacturing processes. Illustration of the principles as they are applied in basic manufacturing operations. (4 cr; prereq MetE 56; 3 lect and 3 lab hrs per wk)

183-184. Principles of Particle Technology. Definition, theory, and measurement of particle properties, particle statistics, fluid dynamic, optional, electrical, thermal behavior of particles, particle transport, gas cleaning, and particle processing. (3 cr per qtr; prereq 31A or ‡; 3 lect hrs per wk)

191-192-193.† Mechanical Engineering Design. Design of mechanical engineering elements and systems. Interdivisional problems involving thermodynamics, mass and heat transfer, solid and fluid mechanics, economics and production, operations analysis, and automatic controls. (2 cr per qtr; prereq 4th-yr engr or ‡; 4 lab hrs per wk)

194. **Advanced Engineering Problems.** Work pertaining to special investigations in the various fields of mechanical engineering. (2-4 cr; open only to 4th-yr ME with a minimum of 2.50 GPA; prereq consent of the chief of division concerned)

197. **System Analysis and Control.** Study of basic theory of linear feedback control systems. The transfer function representation of solid body, fluid, pneumatic, and electro-mechanical components. On-off, proportional, floating, and rate response in control systems, including industrial instrumentation. (3 cr; prereq 23; 2 lect and 3 lab hrs per wk)

198. **Industrial Instrumentation and Automatic Control.** Theory and operation of instruments and automatic controls. Domestic and industrial control mechanisms. On-off, proportional, floating, and rate response in control instruments. (3 cr; prereq 197 or equiv; 2 lect and 3 lab hrs per wk)

199. **Advanced System Analysis and Control.** State space analysis of control systems including Liapunov analysis, controllability and observability. Describing function analysis of nonlinear control systems. Selected optimal control topics such as time optimal control. (3 cr; prereq 197; 3 lect hrs per wk)

For Graduate Students Only

224-225-226. Advanced Applied Dynamics

228. Photoelasticity

229. Advanced Vibration Engineering

230. Advanced Thermodynamics

231. Statistical and Nonequilibrium Thermodynamics

232. Advanced Fluid Thermodynamics

233. Conduction

234. Convection

235. Radiation

236. Advanced Theory of Heat Transfer

242. Advanced Power Plants

246. Energy Transport in Chemically Reacting Gases

247. Mass Transfer in Chemically Reacting Gases

248. Atomization Vaporization and Mixing

250. Dynamics of High Speed Engines

253. Advanced Gas Turbines and Jet Propulsion

255. Advanced Rocket Propulsion

265-266-267. Psychrometrics and Air Conditioning

270-271-272. Magnetohydrodynamics

280. Theoretical Refrigeration

282. Reverse Applications of Refrigeration — Heat Pump

285-286-287. Biomedical-Engineering Seminar

286A. An Introduction to Fluid Mechanics for Biologists and Bioengineers

290-291-292. Mechanical Engineering Research

293. Graduate Seminar

296-297-298. Feedback Control Systems

School of Mineral and Metallurgical Engineering

Metallurgy-Materials Science (MetE)

2. Introduction to Materials. The field of materials science, origins of microstructure, structure-sensitive properties, quality control research and development, technical sales. (2 cr)

56. Physical Metallurgy. Introduction to principles. Theory of metals and alloys, constitution diagrams, heat treatment, relation of structure to properties. (3 cr; prereq 3rd yr)

60. Physical Metallurgy. Theory of metals and alloys, constitution diagrams, heat treatment. Relation of structure to properties. (3 cr; for chemical engineering students; prereq 3rd yr) Staff

90-91-92-93-94.‡ Industrial Employment. Summer work in metallurgical engineering or allied fields for a period of 2 or more months. Character of work to be approved by the school. Satisfactory record of employment and an acceptable report are required. (2 cr per course; prereq ‡)

101-102-103. Introduction to Science of Materials. Introduction to relation between atomic and electronic structure of metals, semiconductors, insulators, and polymers and important properties of materials. (3 cr per qtr; prereq 3rd yr IT students)

104. X Rays. Physics of X-ray diffraction, structure factor, powder patterns, crystal orientation, application to metallurgy and materials science (microradiography), solvus determination, phase equilibria. Structure of cold worked metals. (3 cr; 1 lect, 1 rec, 2 lab hrs per wk)

105. Quantitative Metallography and Electron Microscopy. Microstructure of materials, temperature measurement and control, equilibrium diagrams, quantitative metallography, electron microscopy. (3 cr; 1 lect, 1 rec, 2 lab hrs per wk)

110. Physical Metallurgy Laboratory. Solidification of metals and alloys, transformations in solids, hardenability, surface treatment of metals, metallurgical problems. (3 cr; 1 lect, 4 lab hrs per wk)

141-142-143.*‡ Special Problems in Physical Metallurgy and Materials Science. Library or laboratory studies of scientific or engineering problems in physical metallurgy and materials science. (Cr ar; prereq sr; hrs ar) Staff

153-154-155. Solidification and Transformation of Metals and Alloys. Casting, heat treatment, surface treatment, vapor deposition, thin film technology, cold working and annealing. (3 cr per qtr; prereq 103 or ‡) Nicholson

161. Corrosion of Metals. Electrochemical theory and mechanism of corrosion, generalized film theory. Influence of structure, composition, and mechanical factors on metallic corrosion. Inhibitors, oxidation, corrosion protection. (2 cr; prereq 56, PCh 101 or 101H) Nicholson

167. Control of Mechanical Properties in Metals and Alloys. Mechanical properties of metals and alloys are discussed in terms of dislocation behavior. Attention to *control* of mechanical properties through manipulation of microstructure by metal processing. (3 cr; prereq 102)

168. Deformation Processing of Metals. Introduction to plastic behavior of metals rolling, extrusion wire drawing, deep drawing, theory of textures in metals, relation of textures to properties of metals. Laboratory exercises. (3 cr; prereq 102) Nicholson

169. Analysis of Metallurgical Problems. Specialized metallurgical subjects such as embrittlement of steels, residual stresses, wear, and fatigue in metals. (3 cr; prereq 102)

173. Crystalline Properties of Metals. Geometry and properties of metal crystals. X-ray diffraction, electrical and thermal conductivity, Hall effect, optical properties, and elastic and plastic behavior of metals. (3 cr; prereq 103) Sivertsen, Hutchinson

174. Modern Theory of Metals and Alloys. Free electron theory of metals and application. Imperfection in crystals. (3 cr; prereq 173 or ‡) Sivertsen, Hutchinson

175. Imperfections in Metals. Theory of imperfections and their effects on properties of metals. (3 cr; prereq 174 or ‡) Sivertsen, Hutchinson

180-181. Thermodynamics and Kinetics of the Solid State. Theory of liquids, heterogeneous equilibria, free energy composition diagrams and reaction kinetics. (3 cr per qtr; prereq PCh 101 or course in thermodynamics) Toth

182. Theory of the Structure of Metals and Alloys. Introduction to electronic theory of the structure and cohesive properties of metals and alloys. Development of the wave mechanical description of the energy band structure, density of states curves, and Brillouin zone structure of various metallic crystal systems. Application to the understanding of the cohesive properties of metals and alloys, and relationship to observed structures. (3 cr; prereq 103 or ‡) Sivertsen

For Graduate Students Only

213-214-215.‡ Seminar: Materials Science

250. Thermodynamic Properties of Solids

251-252.* Kinetics of Solid State Reactions

255-256.* Transformations in Microstructure

259. Electron Interaction with Solids

260. Dislocation Theory of Crystals

261-262. Theories of Mechanical Behavior of Solids

263. Advanced X-ray Diffraction of Metals

271-272.‡ Structure and Cohesion of Metals and Semiconductors

280. Topics in Low Temperature Metal Physics

285. High Temperature Properties of Solids

290-291-292.‡ Selected Topics in Physical Metallurgy

Mineral Resources Engineering (MinE)

(School of Mineral and Metallurgical Engineering)

MINING AND PETROLEUM PRODUCTION PROCESSES

1. **Mineral Engineering Laboratory.** The field of mineral resources engineering, including mining and petroleum production processes and mineral and metal extractive processes, described in lectures, laboratories, and field trips. (1 cr; 1 lect or 1 lab hr per wk) Staff

90-91-92-93-94.‡ Industrial Employment. Summer work in mineral dressing, mining, or allied fields for a period of 2 or more months. Character of work to be approved by the school. Satisfactory record of employment and an acceptable report required. (1-3 cr per course; prereq ‡) Staff

112.* Principles of Mineral Engineering I: Development and Exploitation. Development and production systems for mineral properties. Essential criteria for design and selection of mining methods. Unit operations: drilling, blasting, loading, hauling. (3 cr; prereq 3rd yr; 3 lect hrs per wk) Pfleider

113.* Principles of Mineral Engineering II: Earth Fluids and Flow. Sedimentary rock and earth fluids characteristics. Fluid flow through porous rocks. Basic principles of oil reservoir engineering; energies and mechanisms of petroleum production. (3 cr; prereq 3rd yr; 3 lect hrs per wk) Lacabanne

120.* Mine and Mill Plant Engineering I. Electrical considerations in mine and mill plants. Principles, advantages, disadvantages, selection of electrical machines. Electrical control systems. Power distribution. (3 cr; prereq Phys 23T or ‡; 3 lect hrs per wk) Staff

121.* Mine and Petroleum Plant Engineering II. Basic engineering principles in design and selection of mine, petroleum, and mill plant equipment. Calculations involving compressed air, pumping, transmission of gases and fluids, and power systems. (3 cr; prereq 120 or ‡; 3 lect and 3 lab hrs per wk) Dorenfeld

122.* Mine Plant Engineering III. Basic engineering principles in design and selection of mine plant equipment. Calculations involving power transmission and drilling, transporting, and hoisting of materials. (3 cr; prereq 121, CE 101A; 4 lect hrs per wk) Dorenfeld

123.* Mine Air Conditioning. Mine gases, dust control, and physical properties of air; measurement of air properties. Design of ventilation, heating, and refrigeration systems. (3 cr; prereq 112; 3 lect and 3 lab hrs per wk)

126-127.* Operations Analysis in Mineral Engineering I, II. Problems of variations in capital and operating costs; products specifications. Statistical methods, tests of significance, correlation techniques; applications to cost estimates, sampling, mine and mill operations, blending, automation, and optimization techniques. (3 cr per qtr; prereq 121 or ‡; 3 lect hrs per wk) Dorenfeld

137.* Computer Applications in Mineral Engineering. Finite difference techniques and their applications to ore reserve estimates and mine haulage problems. Solution of linear equations, regression analysis, and curve fitting. Iterative methods and ventilation network analysis. Brief introduction to use of random numbers, simulation, and computer models. (3 cr; prereq Math 30 or 65 or ‡) Starfield

139.* Engineering Field Study. Study of mining and petroleum operations; mine and petroleum plants and metallurgical plants in selected regions. (3 cr; prereq ‡; hrs ar) Staff

141.* Mineral Economics I: Examination and Valuation of Mining and Petroleum Properties. Geologic factors and mineral laws. Sampling and reserve estimates. Analysis of costs and profitability. Taxation, depreciation, and depletion. Present worth and rate-of-return computations; financing methods. (3 cr; prereq 112 or 113 or ‡; 3 lect hrs per wk) Pfleider

142.* Mineral Economics II: Minerals in National and World Affairs, Their Importance and Distinctive Features. Distribution, demand, and conservation of strategic supplies. Marketing and prices. State and national policies affecting development. Analysis of mineral data. (3 cr; prereq Geo 62 or ‡; 3 lect hrs per wk) Pfleider

144-145.* Mineral Engineering Design. Systems design in the exploration, development, and exploitation of a mineral property. Integration of concepts from geology and geophysics, rock mechanics, mine or petroleum plant engineering, and mineral economics and valuation principles to a specific problem chosen by student. Preparation of report. (2 cr for 144, 4 cr for 145; prereq 142 or ‡; 6 lab hrs per wk for 144, 9 lab hrs per wk for 145) Pfleider and staff

151, 152, 153.*† Special Mineral Engineering Problems. Literature survey or research work on mining problems. (Cr and hrs ar; prereq 112)

155.* Surface Mining Engineering. Unit operation of drilling, blasting, loading, and transportation of surface rocks and soils. Equipment productivity, selection, and cost estimating. Design of open pits and quarries. Economics and organization. (3 cr; prereq 112 or 131 or ‡) Pfleider

156.* Gravity Flow of Fragmented Materials. Index, strength and flow properties of fragmented materials. Flow—no-flow design principles and techniques for gravity bins and drawpoints. Rate of discharge formulas, model consideration. Engineering problems and laboratory exercises. (2 cr; prereq 3rd yr or ‡) Pfleider, Fairhurst, Starfield

171.* Fluid Flow Through Porous Media I. Introduction; petrophysics of porous rocks and aquifers; porosity, permeability, surface areas; linear, radial, and spherical flow; incompressible and compressible fluids; Darcy's Law; units; combination flows; etc. (2 cr; prereq 113 or ‡; 2 lect hrs per wk) Lacabanne

171A.* Fluid Flow Laboratory I. Core analyses; porosity, permeability saturation measurements; linear and radial flows with liquids and gases, liquid vertical flows; etc. (1 cr; prereq 171 or ‡; 3 lab hrs per wk) Lacabanne

172.* Fluid Flow Through Porous Media II. Flow possibilities; Darcy's generalized equations; vertical flow equations, units; Kozeny equation; fracture and channel flow; diffusivity equation and unsteady state flow; electrical and acoustical properties of rocks — porosity and connate water relationships; etc. (3 cr; prereq 171 or ‡; 3 lect hrs per wk) Lacabanne

172A.* Fluid Flow Laboratory II. Capillaries and networks; Kozeny relationships — also electrical relationships; internal surface area measurement methods; pore size distributions; capillary pressures; electrical properties of rocks, formation factors, relationships to porosity and water saturations; water resistivities; etc. (1 cr; prereq 172 or ‡; 3 lab hrs per wk) Lacabanne

173.* Fluid Flow Through Porous Media III. Behavior and flow of oil, gas, and water in reservoirs; reservoir flow energies and mechanisms; evaluation of reserves, material balance equations; rock compressibility effects on recoveries;

mobility ratios; fractional flow equations; etc. (2 cr; prereq 172 or ‡; 2 lect hrs per wk) Lacabanne

MINERAL AND METAL EXTRACTIVE PROCESSES

106.* **Principles of Process Metallurgy I.** Material and heat balances in metallurgical processes. Combustion of fuels and heat utilization. Phases in pyrometallurgical systems. (3 cr; prereq 8 cr inorganic chemistry) Bitsianes

107.* **Principles of Process Metallurgy II.** Fluid flow and heat transfer concepts in metallurgical systems. Theory and correlations to industrial practice. Laboratory investigations in process metallurgy. (4 cr; prereq 106 or ‡) Bitsianes

108.* **Metallurgical Unit Processes.** Equilibrium and rate concepts in metallurgical processes. Roasting, agglomeration, smelting, and refining of liquid metals. The integrated process. (3 cr; prereq 107 or ‡) Bitsianes

114.* **Mineral Processing I.** Practice and theory of comminution. Volumetric and gravimetric sizing; practice and principles of classification. Laboratory investigation of crushing, grinding, size analysis, and size of liberation of ores. (3 cr; prereq Geo 62 or ‡) Cooke

115.* **Mineral Processing II.** Principles of ore beneficiation by gravity and other processes. Material balances. Elementary ore flotation. Laboratory concentration of ores. (3 cr; prereq 114) Cooke

116.* **Mineral Processing III.** Principles of flotation. Theory of frothing, collecting, depressing, activating, conditioning. Laboratory experiments to illustrate theory and bench-scale operations. (3 cr; prereq PCh 108) Cooke

117-118.*‡ **Metallurgical Engineering Design.** Methods used in selection of metallurgical plant equipment, problems of scale-up from pilot-plant and laboratory data; integration of equipment into a working plant and its economics, construction, and operation. (2 cr for 117, 4 cr for 118; prereq 115, 121; 3 lect hrs per wk) Dorenfeld

160.* **Hydrometallurgy I.** Application of physicochemical principles to the leaching of ores and concentrates, to purification of leach liquors, and recovery of metals from solutions. (3 cr; prereq 116 or ‡) Cooke

161.* **Hydrometallurgy II.** Principles of ion exchange and solvent extraction. Integration of operations and processes on a plant basis. Applications in nonferrous metallurgy. (3 cr; prereq 160) Cooke

162.* **Electric and Magnetic Separation of Minerals.** Electric separation of dielectric minerals using electrostatic fields, and separation of conductors from insulators by corona discharge. Laboratory methods for determining electric properties of minerals and laboratory experiments using high and low intensity magnetic separators. (2 cr; prereq 116; 1 lect and 3 lab hrs per wk) Lawver

163.* **Techniques of Mineral Processing Research I.** Experimental design and data analysis with applications of digital computers. Experimental methods of determining optimum conditions; path of steepest ascent; response surface methodology; evolutionary operation; sampling theory; the laboratory notebook and industrial patent law; report writing. (3 cr; prereq PCh 107 or ‡; ME 99 or MinE 126 or ‡) Lawver

164.* **Techniques of Mineral Processing Research II.** Introduction of experimental techniques. Physicochemical methods: photographic principles; emission spectroscopy; adsorption spectrophotometry; radiotracer techniques; electrochemical and electrokinetic measurements; chromatography; surface area determination. (3 cr; prereq PCh 107 or 108 or ‡) Cooke

165.* **Techniques of Mineral Processing Research III.** Physical methods; optical microscopy; differential thermal and thermogravimetric analysis; electron microscopy; X-ray diffraction and fluorescence; electron probe microanalysis; electrical and magnetic properties of solids; preparation of a graduate thesis. (3 cr; prereq Phys 50T or ‡) Staff

166.* **Physical Chemistry of High-Temperature Metallurgical Reactions I.** Physicochemical principles as applied to iron and steelmaking. Thermodynamics of liquid steel. Reactions in liquid metal solutions. (3 cr; prereq 108 or ‡) Bitsianes

167.* **Physical Chemistry of High-Temperature Metallurgical Reactions II.** The liquid slag state and slag constitution theories. Slag-metal distribution equilibria. The phosphorous and sulfur problems in iron and steelmaking. (3 cr; prereq 166) Bitsianes

168.* **Physical Chemistry of High-Temperature Metallurgical Reactions III.** Kinetics and rates of reaction in iron and steelmaking. Mass transport processes. Applications to metallurgical systems. (3 cr; prereq 167) Bitsianes

169.* **Advanced Process Metallurgy.** Application of physical chemistry to some advanced problems in metallurgical engineering. Heterogeneous chemical reactions. (2 cr; prereq 166) Bitsianes

181-182-183.*‡ **Special Problems in Extractive Metallurgical Engineering.** Laboratory investigation of problems in extractive metallurgy. (Cr ar; prereq sr; hrs ar) Staff

For Graduate Students Only

201-202-203-204-205-206-207-208-209.*‡ **Seminar: Mineral Engineering**

210.*‡ **Advanced Engineering Design**

212-213-214.*‡ **Mining Research Problems**

221-222-223.*‡ **Research in Extractive Metallurgical Engineering**

230-231-232.*‡ **Seminar: Extractive Metallurgical Engineering**

240.* **Advanced Concepts in Drilling of Rocks**

241.* **Advanced Mineral Economics I**

260.* **Flotation Theory**

262.* **Surface Chemistry of Flotation**

Natural Science (NSci)

4-5.† **The Physical World.** Essential elements of physics and chemistry, selected to illustrate the methods of modern science and to acquaint the student with the physical universe around him. Laboratory work is an integral part of the course. (4 cr per qtr, §equiv courses in science departments; prereq 9th grade algebra)

School of Physics and Astronomy

Astronomy (Ast)

11. Descriptive Astronomy. Brief survey of what is known about the sun, the moon, the planets and their motions, followed by a description of the constellations and a summary of our knowledge of the stellar universe to which the sun belongs. This course is completely nonmathematical. (5 cr, §51)

51. Introduction to Astronomy and Astrophysics. A survey of the known facts about the solar system, galaxy, and extragalactic universe. Discussion of the manner in which the information is obtained, and some of the conclusions that can be inferred from these observations. Course is more physical and mathematical than Ast 11. (3 cr, §11; prereq 1 yr calculus and Phys 9 or 6 or 23T, or ‡)

121-122-123. Astrophysics and Stellar Statistics. Introductory course on the motions of the stars. (3 cr per qtr)

161.* Astrophysics of Diffuse Matter. Discussion of diffuse matter in the solar system, interstellar and extragalactic space, and the radiation field in these environments. Topics include gaseous nebulae, radio astronomy and nonthermal radio sources, cosmic rays, and some aspects of cosmology. (3 cr; prereq 51 and Phys 50 or 50T or ‡)

162.* Astrophysics of Condensed Matter. The luminosities, temperatures, masses, and densities of stars, together with their mechanisms for energy generation. The chemical composition of stars and the probable course of stellar evolution. (3 cr; prereq 51, Phys 50 or 50T or ‡)

Physics (Phys)

1-2-3. Introductory Physics. Demonstration lectures on the principles of physics and physical phenomena underlying these principles. 1: Mechanics. 2: Heat, electricity, and magnetism. 3: Wave motion and light. (3 cr per qtr; prereq high school algebra and plane geometry for 1...1 or ‡ for 2...2 or ‡ for 3; 3 lect hrs per wk)

1A-2A-3A. Introductory Physics Laboratory. Laboratory course given in conjunction with 1-2-3. (1 cr per qtr; prereq 1-2-3 or ¶1-2-3; combination of 1-2-3 with 1A-2A-3A may be used to fulfill the laboratory science group requirement in CLA but does not serve as prereq for advanced physics courses; 2 lab hrs per wk; offered P-N only for CLA, AFHE)

4-5-6. General Physics. 4: Mechanics. 5: Heat and electricity. 6: Sound and light. Laboratory work is an integral part of course. (5 cr per qtr; primarily for premedical students; prereq Math 40A or ¶Math 40A or equiv for 4...4 for 5...5 for 6; 4 lect, 1 quiz, 2 lab hrs per wk)

7-8-9. General Physics. 7: Mechanics. 8: Heat, electricity. 9: Sound and light. Laboratory work is an integral part of course. (5 cr per qtr; primarily for students majoring in physics, mathematics, or chemistry; prereq Math 22A or Math 42, Math 23A or ¶Math 23A or Math 43 or ¶Math 43 for 7...7 and Math 44 or ¶Math 44 for 8...8 for 9; 4 lect, 1 quiz, 2 lab hrs per wk)

20. Elementary Physical Acoustics. Physical principles of acoustics and wave motion with particular application to the field of music and musical instruments.

Laboratory work is an integral part of the course. (5 cr, §Phys 3, §Phys 6, §Phys 9, §Phys 22; primarily for music and music education majors; prereq 1 yr high school algebra)

21. **General Physics.** Classical mechanics. (4 cr; prereq ¶21A, Math 22A or ¶Math 22A or Math 42 or ¶Math 42; 4 lect and 1 quiz hr per wk)

21A. **Physics Laboratory.** Laboratory exercises in mechanics. (1 cr; prereq ¶21; 2 lab hrs per wk; offered P-N only for CLA, AFHE)

22T. **General Physics.** Relativistic kinematics, electricity and magnetism. (4 cr, §23; prereq 21, ¶22A, Math 23A or ¶Math 23A or Math 43 or ¶Math 43; 4 lect and 1 quiz hr per wk)

22A. **Physics Laboratory.** Laboratory exercises in electricity and magnetism. (1 cr; prereq ¶22T; 2 lab hrs per wk)

23T. **General Physics.** Mechanical and electrical waves; physical and geometrical optics; particle nature of light; wave nature of matter. (4 cr; prereq 22T or 23, ¶23A; 4 lect and 1 quiz hr per wk)

23A. **Physics Laboratory.** Laboratory exercises in waves and optics. (1 cr; prereq ¶23T; 2 lab hrs per wk)

23H. **Honors Course: General Physics.** Mechanical and electrical waves, physical and geometrical optics; particle nature of light, wave nature of matter; quantization of particles in a box. (4 cr; prereq 22T, ¶24H, △; 4 lect and 1 quiz hr per wk)

24H. **Honors Course: Physics Laboratory.** Parallel to Phys 23H. (1 cr; prereq ¶23H, △; 3 lab hrs per wk)

50T. **Modern Physics.** Quantum mechanics, hydrogen atoms, atoms and molecules, quantum distribution, and topics in solid state, nuclear physics, and astrophysics. (4 cr; prereq 6 or 9 or 23 or 23T, Math 31 or Math 44; 4 lect and 1 quiz hr per wk)

50A. **Physics Laboratory.** Parallel to Phys 50T. (1 cr; prereq ¶50T; 2 lab hrs per wk)

50H. **Honors Course: Modern Physics.** Honors course parallel to Phys 50T. (4 cr; prereq 23H, Math 32 or ¶Math 32 or Math 55 or ¶Math 55, △; 4 lect and 1 quiz hr per wk)

51T. **Statistical Physics.** Statistical description of systems, thermal interactions, canonical ensemble, macroscopic properties, Maxwell distribution, statistical approach to thermodynamics, transport phenomena. (4 cr; prereq 6 or 9 or 23 or 23T, Math 31 or Math 44; 4 lect and 1 quiz hr per wk)

51A. **Physics Laboratory.** Parallel to Phys 51T. (1 cr; prereq ¶51T; 2 lab hrs per wk)

51H. **Honors Course: Statistical Physics.** Honors course parallel to Phys 51T. (4 cr; prereq 50H, △; 4 lect and 1 quiz hr per wk)

52H. **Honors Course: Physics Laboratory.** Parallel to Phys 50H. (1 cr; prereq ¶50H, △; 3 lab hrs per wk)

53H. **Honors Course: Physics Laboratory.** Parallel to Phys 51H. (1 cr; prereq ¶51H, △; 3 lab hrs per wk)

60-61. **Intermediate Physics.** Atomic, molecular, and nuclear physics emphasizing implications for the biological sciences. Topics selected from: atomic, molecular, and nuclear structure; interaction of electromagnetic radiation with matter;

radioactivity; hydrodynamics; thermodynamics; kinetic theory and elementary statistical mechanics; transport phenomena; reaction kinetics. (3 cr per qtr; primarily for premedical students and students majoring in biological sciences; prereq 6 and Math 40 or △)

70. Industrial Summer Employment. Employment (contracted by the student) with an industrial firm in a professional or semi-professional capacity doing work in the field of physics. Applications must be approved by the department prior to employment. Ten weeks of summer employment with a written report on this work approved by both employer and the department. (1 cr; prereq 3 yrs of academic work, △ during previous spring qtr)

71. Directed Study. Independent, directed study in physics, in areas arranged by the student and a faculty member. (1-5 cr ar; prereq ‡, △)

100-102-104.* Mechanics, Electricity, and Magnetism. Theoretical course designed to prepare students for advanced work. (4 cr per qtr, §100A or §MM 138 for 100; prereq 9 or 23T, Math 32 or Math 55 for 100...100 or MM 138 for 102...102 for 104; 4 lect hrs per wk)

100A-101A-102A.* Introduction to Analytic Mechanics. Analytic course in Newtonian mechanics with emphasis on conservation principles. Topics include: particle dynamics in 1, 2, and 3 dimensions with special attention to the central force problem; dynamics of a system of particles including general motion of a rigid body and normal mode analysis of coupled systems; moving coordinate systems; mechanics of continuous media, wave motion and elementary hydrodynamics; general coordinates and the Lagrange formulation of mechanics. Mathematics beyond the prerequisites is developed as required. (3 cr per qtr, §100 for 100A, §100 or §MM 138 for 101A; prereq 9 or 23T, Math 32 or Math 55 for 100A...majors in fields other than physics may use MM 138 as prereq for 102A; 3 lect hrs per wk)

103A-104A-105A.* Introduction to Electric and Magnetic Fields. Classical theory of electric and magnetic fields making free use of vector algebra and vector calculus. Maxwell's equations developed from basic experimental laws in form applicable both to free space and to material media. Wave solutions for these equations discussed, with application to simple situations. (3 cr per qtr; prereq 9 or 23T, Math 32 or Math 55 for 103A)

108-110-112.* Principles of Modern Physics. Combines elementary quantum mechanics with its historical background and applications to atomic and nuclear physics. Origin of quantum theory, electrons and quanta, atomic structure, particles and waves, the theory of quantum mechanics, one-electron atoms, exclusion principle, multi-electron atoms, X rays, scattering, and nuclear physics. (3 cr per qtr; prereq 51 or 50T, ¶Math 33 or ‡)

113.* Techniques of Nuclear Physics. Statistics of random events; interactions of photons, charged, and neutral particles with matter; detection devices; beam handling; measurement and analysis of cross sections. (3 cr)

114-116-118.*‡ Elementary Physical Investigation. Problems, either experimental or theoretical, of special interest to student. Written report required. (Cr ar; prereq 3rd yr, △)

120-121-122.*‡ Experimental Atomic and Nuclear Physics. Techniques and methods used in physics research laboratories. Experiments deal with vacuum gauges and equipment; mass spectroscopy; X-ray diffraction; health physics; detection of charged particles, neutrons and gamma rays; and the measurement of several fundamental atomic constants. (3 cr; prereq 51 or ¶107 or

¶108, ‡; 6 lab hrs per wk; a student may take 1 or 2 qtrs of this sequence in any order)

123.* **Thermodynamics.** Formulation of the basic laws of thermodynamics concerning temperature, energy and entropy; application to simple systems. (3 cr per qtr; prereq 9 or 23T, Math 32 or Math 55)

124.* **Statistical Mechanics.** Introduction to transport phenomena; principles of statistical mechanics with applications to equilibrium properties of classical and quantum systems. (3 cr; prereq 123 or ‡)

125.* **Introduction to Solid State Physics.** Structure; thermal, magnetic and dielectric, and electronic properties of crystalline solids. (3 cr; prereq 124 or ‡)

131.* **Geometrical Optics.** Fundamentals of ray optics and study of its applications to optical instruments and their components. (3 cr; 15 cr in physics, Math 23A or Math 43)

133.* **Physical Optics.** Wave theory of interference, diffraction, polarization, and double refraction, with a study of their applications. (3 cr; 15 cr in physics, Math 23A or Math 43)

133A.* **Physical Optics Laboratory.** Parallel to Phys 133. (1 cr; prereq 133)

134.* **Experimental Optics Laboratory.** Selected experiments on interference, coherence, diffraction, polarization, and dispersion; atomic spectra; electro- and magneto-optics; thin films; crystal optics; microwaves, optical pumping, and lasers; holography; spatial filtering; nonlinear optics; imaging systems. (3 cr; prereq 15 cr in physics, Math 23A or Math 43)

135.* **Contemporary Optics.** Selected topics, with emphasis on the laser and its applications. Wave theory: interference, multiple films, coherence. Quantum phenomena, detectors. Stimulated emission, gas and solid state lasers. Holography and spatial filtering. Symmetry, crystals, and light. Nonlinear optics, electro- and magneto-optics, harmonic generation. (3 cr; prereq 133 or familiarity with wave phenomena)

136.* **Spectrum Analysis Laboratory.** Measurement of wave lengths, intensities, and absorption coefficients in the infrared, visible, and ultraviolet regions of the spectrum. (3 cr; 15 cr in physics, Math 23A or Math 43)

146.* **Vacuum Tube and Transistor Circuits.** Basic DC and AC-circuit analysis; large- and small-signal analysis of diode, transistor, and vacuum tube circuits. (4 cr; prereq 9 or 23 or 22T, Math 31 or Math 44; 3 lect and one 3-hr lab per wk)

148.* **Applications of Electronic Circuits.** Uses of electronic cricuits, feedback amplifiers, oscillators, waveform generation and shaping; balanced circuits. (4 cr; prereq 146; 3 lect and one 3-hr lab per wk)

149.* **Electronic Measurements.** Measurement of voltage, current, and impedance; signal analysis, measuring instruments used in physics research. (4 cr; prereq 148; 3 lect and one 3-hr lab per wk)

150.* **History of 20th Century Physics: The Origins and Developments of Quantum Mechanics.** Selected original papers and secondary historical accounts will be read and discussed. The course will encompass the following topics: Black-body radiation laws and the origins of the concept of quanta in the work of Planck. The early contributions of Einstein, X rays, γ rays, and early particle-wave questions up to von Laue (1912). Spectra and the Bohr atom. The Old Quantum Theory: Bohr, Sommerfeld, and others; Correspondence Principle, Multiplet Structure (Zeeman and Stark Effects), Exclusion Principle and Spin. The

Compton Effect and the Transition to Quantum Mechanics. Heisenberg and Matrix Mechanics. L. de Broglie, Schroedinger, and Wave Mechanics. Contributions of Born, Dirac, and others. Uncertainty principle. Conclusions. (3 cr; prereq ‡)

151.* History of 19th-Century Physics: The Nature and Interactions of Light. The primary focus of the course will be on the establishment of the wave theory through the work of Young, Fresnel, Foucault, and others; theories of the ether; the work of Faraday; the establishment of the electromagnetic wave theory through the work of Maxwell, Hertz, and others; spectral studies of Ritter, Melloni, and others; the Lorentz theory of electrons. Related topics, such as the discovery of the conservation of energy, will be discussed when appropriate. (3 cr; prereq ‡)

160A-B-C.*‡ Senior Seminar. (Cr ar; primarily for senior physics majors; prereq Δ)

165.* Introduction to Physics of the Atmosphere. A survey of the physical processes which determine the mean state of the atmosphere. Topics in radiative transfer and thermodynamics are reviewed in preparation for the discussion of the heat budget and temperature distribution of the atmosphere. Atmospheric properties and phenomena treated include: formation of clouds and precipitation, convection and stability, atmospheric electricity and ozone. (3 cr; prereq 23T, Math 33 or Math 147)

166.* Meteorology I. Quantitative description of large-scale atmospheric motions. The basic equations of meteorological hydrodynamics are introduced and applied in actual weather situations. (3 cr; prereq 165 or ‡)

167.* Meteorology II. Theoretical meteorology. Critical examination of the mathematical models used to describe the large-scale flow processes; energy transformations in atmospheric flow; atmospheric turbulence and eddy transport. (3 cr; prereq 166, vector analysis or ‡)

171A-B-C.* Classical Physics. Classical mechanics, special theory of relativity, and classical electrodynamics. Application of advanced mathematical techniques to these subjects. (4 cr per qtr; prereq 104 or both 102A and 105A, Math 153 or Math 108, ‡; 3 lect hrs and 1 prob session per wk)

181A-B-C.* Quantum Mechanics. Development from first principles. Schrodinger equation, angular momentum, scattering, matrix representations, spin, approximation methods, interaction with the electromagnetic field, systems of identical particles, applications to atomic systems. (4 cr per qtr; prereq 110 or equiv, Math 153 or Math 108 or equiv, ‡; 3 lect hrs and 1 prob session per wk)

190.* Introduction to Elementary Particle Physics. Discussion and analysis of experiments used to study the properties of elementary particles and the theoretical ideas currently being used to interpret the experimental results. (3 cr; prereq 181B, ‡)

192.* Atomic and Molecular Structure. A discussion of atomic and molecular structure, with emphasis on the interpretation of quantum numbers and selection rules in terms of symmetry. The experimental data will be summarized and compared to the theoretical predictions. (3 cr; prereq 181C or ‡; offered 1968-69 and alt yrs)

194.* Introduction to Contemporary Problems in Cosmic Ray and Space Physics. Discussion of cosmic rays, their characteristics, and their motion in the interplanetary and interstellar medium. Topics in X-ray and radio astronomy will also be discussed. (3 cr; primarily for students specializing in other branches of physics; prereq ‡; offered 1970-71 and alt yrs)

196.* Propagation and Detection of High Energy Particles and Electromagnetic Radiation. Is effectively the first quarter of the cosmic ray sequence but may be taken by students specializing in other branches of physics. Treats the propagation of energetic particles and electromagnetic radiation through different types of matter, relativistic collisions, considerations relating to particle counting and detection, and various types of detectors. (3 cr; prereq 112, 171C or ‡)

198.* Introduction to Astrophysics. The fundamental physics required for understanding astrophysics will be presented. The equations of state of normal and degenerate matter, the physics of energy generation by nuclear processes, stellar opacity, equations of stellar structure, and cosmic astrophysics will be treated. (3 cr; prereq 110 and 124 or equiv, or ‡; offered 1970-71 and alt yrs)

For Graduate Students Only

201A-B-C.* Dynamics of Fluid Motion

204.* Equilibrium Statistical Mechanics

205.* Transport Theory

206.* Introduction to Plasma Physics

208.* Symmetry and Its Applications to Physical Problems

209A-209B.* General Relativity

210A-B-C.* Seminar: Theoretical Physics

211.* Advanced Quantum Mechanics

212.* Relativistic Quantum Mechanics

213.* Relativistic Quantum Field Theory

216.* Many-Body Theory

220A-B-C.* Seminar: Nuclear Physics

225.* Nuclear Structure

226.* Nuclear Reactions and Scattering

227.* Advanced Topics in Nuclear Physics

230A-B-C.* Seminar: Solid-State and Low-Temperature Physics

231A-B.* Solid-State Physics

232.* Magnetism (same as EE 200C)

233.* Superconductivity

234.* Techniques of Low-Temperature Physics

235.* Liquid and Solid Helium

236.* Magnetic Resonance in Solids

238.* Advanced Topics in Solid-State and Low-Temperature Physics

240A-B-C.* Seminar: Elementary Particle Physics

241A-B.* Elementary Particle Physics

243.* Advanced Topics in Elementary Particle Physics

250A-B-C.* Seminar: Cosmic Ray and Space Physics

251A-B.* **Cosmic Ray and Space Physics**

252A-B.* **Solar and Magnetospheric Physics**

253A-B.* **Plasma Physics**

254.* **Advanced Topics in Plasma Physics**

256.* **Advanced Topics in Atmospheric Physics**

257.* **Origin and Evolution of the Solar System**

258A-B-C.* **Astrophysics**

260A-B-C.* **Seminar: Mass Spectroscopy**

270A-B-C.* **Seminar: Atmospheric Physics**

280A-B-C.* **Seminar: Problems of Physics Teaching and Higher Education**

290A-B-C.*‡ **Seminar: History of 20th-Century Physics**

301A-B-C.*‡ **Research in Physics**

Russian (Russ)

(College of Liberal Arts)

1-2-3. Beginning Russian. Provides basic experience in speaking, reading, and understanding the Russian language and its structure through the acquisition of basic patterns of speech. (5 cr per qtr)

Soil Science (Soil)

(College of Agriculture, Forestry, and Home Economics)

19. Introductory Soil Science. A study of basic physical, chemical, and microbiological properties of soil. Soil genesis, classification, and principles of soil fertility. Lectures, laboratory. (4 cr, §18; prereq ¶GeCh 5 or registered in technical certificate program)

Statistics (Stat)

(College of Liberal Arts)

90E. Introduction to Probability and Statistics. Elementary probability and probability distributions. Elements of inference. Separate section of Stat 90. (3 cr; prereq 2nd yr IT or ‡)

131-132-133. Theory of Statistics. 131: Probability models, univariate and bivariate distributions, independence, basic limit theorems. 132-133: Statistical decision theory, sampling, estimation, testing hypotheses, parametric and nonparametric procedures for one-sample and two-sample problems, regression, analysis of variance. (3 cr per qtr; prereq ¶Math 55 for 131, ¶107-108 for 132-133, or equiv)

Zoology (Zool)

(College of Biological Sciences)

71. **Principles of Invertebrate Biology.** The basic characteristics of the invertebrates (exclusive of insects) with emphasis on functional, adaptive, and evolutionary principles. Laboratory will include original research. (5 cr; prereq Biol 2 or 50) Williams

96. **Organic Evolution.** Survey of evidence for and causes of evolution. (3 cr; prereq Biol 2 or 50) Merrell

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