Cornell University

Announcements

Graduate School
Physical Sciences

1971-72

CORNELL UNIVERSITY ANNOUNCEMENTS

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The business office of the Graduate School and the Office of the Dean are in Sage Graduate Center. Office hours are 8:30 a.m. to 4:15 p.m., Monday through Friday. The office is closed on Saturday.

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Professors-at-Large are distinguished nonresident members of the University faculty. During short visits to the campus, of up to a month's duration, made at irregular intervals, they hold seminars, give public lectures, and consult informally with students and faculty.

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Contents

The courses and curricula described in this *Announcement*, the teaching personnel listed herein, and the dates shown in the Graduate School Calendars are subject to change at any time by official action of Cornell University.

Cornell University

Graduate Education at Cornell

Graduate education at Cornell is based on the principle that no objective of a university lies deeper in its tradition or springs higher in its aspiration than does the nurture of scholarship. The advancement of learning, the methods of learning, and the criticism of learning occupy the highest reaches of university life and work. Graduate education brings into fruitful contact the most distinguished scholars and the most advanced students, that learning may be shared and that wisdom may be at least glimpsed.

The Graduate School provides an environment within which scholarly capability is encouraged to emerge, thrive, and transmit itself. The School arranges a set of conditions congenial to the student who is prepared to profit from the availability of advanced courses of study; the opportunity for sustained reflection; the companionship of active, full-time fellow students; the most highly developed libraries, laboratories, and other facilities for research; the prospect of independent discovery or recovery, of evaluation or revaluation; the daily presence of distinguished teachers; and the hope of attaining a firmly based structure of knowledge and a free and independent habit of judgment.

Freedom and independence are key qualities of scholarship, and graduate studies at Cornell are ordered so as to preserve them for both teacher and student. The Cornell principle is that scholars are begotten by other scholars, that judgments are formed by associating with the best judges, that learning lives in the unbroken succession of the learners and the learned, that genuine scholarship is always humane and rests ultimately on personal teaching and personal learning, that success in graduate studies must consist of satisfying the professor rather than a mute schedule of requirements. Graduate School standards are high, but they are maintained there not by the pronouncements of an office but rather by the men after whom such standards are themselves fashioned.

The Cornell graduate student selects not only the study he wishes to pursue, but also the scholar under whose tutelage he wishes to pursue it.

The candidate himself, no one else, makes the choice. Some candidates when they apply for admission have in mind the man or men with whom they wish to study. Those who do not are granted, under a temporary adviser, a semester in which to form an acquaintance and to come to a decision. The supervising professor is called the student's chairman. The chairman and his associate or associates, also chosen by the student, form the student's Special Committee. All such matters as the outlines of study, the observation of progress, the setting of general examinations, the conduct of the thesis, and other exercises leading to a graduate degree are determined within this small circle—the student and the professors he has selected to direct him. So successful is this arrangement and so strongly does Cornell believe in it, that the Special Committee enjoys extraordinary freedom and independence in conducting the student to his degree. The Graduate School sets no course requirement, no credit-hours requirement, no grade requirement. Within the broad agreements of the Graduate Faculty concerning residence, oral examinations, and thesis, the student will be recommended for his degree whenever his Special Committee judges him ready to receive it. When the Committee is satisfied, the requirements are.

The Cornell Graduate School has an enrollment of 3,500 students, and the Graduate Faculty consists of about 1,100 members. In contrast to many other graduate schools, approximately 98 percent of the students are full-time degree candidates, with the majority in programs leading to the Ph.D. degree.

The responsibility for administration of policies and procedures, including the general requirements, the establishment of Fields and subjects for study, admissions, and maintenance of records is placed in the hands of the dean and his staff under the guidance of the General Committee of the Graduate School. These matters are described in detail in *The Code of Legislation,* copies of which may be obtained by enrolled students from the Graduate School Office and which are also available for consultation in other academic and administrative offices of the University.

The University expects that all graduate students at Cornell University shall, at all times, act with a mature and morally responsible attitude, recognizing the basic rules of society and the common rights of others.

Admission

It is the policy of Cornell University actively to support the American ideal of equality of opportunity for all, and no student shall be denied admission or be otherwise discriminated against because of race, color, creed, religion, or national origin.

Since instruction in the Graduate School is primarily individual, those interested in becoming students are encouraged to communicate with individual members of the faculty with whom they may want to study. Personal interviews in advance of formal application for admission are especially encouraged. For the benefit of those who are not acquainted with appropriate members in the Field or Fields of their interest, each Field has selected a representative, as director of graduate studies, to whom inquiries may be addressed.

An applicant for admission to the Graduate School must (1) hold a baccalaureate degree granted by a faculty or university of recognized standing or have completed studies equivalent to those required for a baccalaureate degree at Cornell, (2) have adequate preparation for graduate study in his chosen field of instruction, (3) have fluent command of the English language, and (4) present evidence of promise in advanced study and research. Students from United States colleges and universities should be in the top third of their graduating class.

Applications for admission should be requested from the Graduate School, Sage Graduate Center, Cornell University, Ithaca, New York 14850. Two letters of recommendation should be sent from the applicant's major instructors. Official transcripts from all the institutions of higher learning attended and, where required, the Graduate Record Examinations or the Miller Analogies Test scores complete the application.

All applications from residents or citizens of the United States or Canada must be accompanied by a $15 nonrefundable fee. Applicants from other countries who are accepted for admission must pay this fee before registration.

Fellowship and admission applicants are urged to take the Graduate Record Examinations (GRE) Aptitude (Verbal and Quantitative) Tests of the Educational Testing Service no later than December, and to have the scores sent to the Cornell Graduate School as part of their application materials. Information about the times and places of test administrations may be obtained directly from the Educational Testing Service, Princeton, New Jersey 08540. The Field listings, pp. 50 ff., should be consulted for Fields requiring the scores of both the Aptitude Test and the pertinent Advanced Test.

Foreign applicants whose native language is not English and who have received their secondary or advanced education in the English language should submit to the Graduate School a statement to this effect signed by a responsible officer of a United States Embassy or Consulate or by an appropriate official of the educational institution involved. If English has not been the medium of instruction, applicants must take the Test of English as a Foreign Language by arrangement with Educational Testing Service, Princeton, New Jersey 08540. This testing program is available throughout the world. The test is given four times a year; information on times and places may be obtained directly from the address given above. The test score must be reported directly by the testing organization to the Graduate School; since this test is diagnostic, no final action on applications will be taken until the scores have been received. Admission to those applicants whose scores indicate unsatisfactory command of English may be denied, or it may be made contingent upon evidence of improvement.

Many Fields will not accept new students for the spring term; applicants should check with the Field Representative about the Field's policy on spring admissions.

Categories of Admission

DEGREE PROGRAMS. It is expected that most applicants for admission intend to pursue a program for an advanced degree. Applicants may specify candidacy for the Master of Arts or Master of Science or one of the professional Master's degrees listed on pp. 24–28. However, since Cornell has a strong commitment to doctoral work, most students are encouraged to enroll in a doctoral program. In some Fields, students registered in a doctoral program may be required to seek a Master's degree as an initial step in the program.

Only under unusual circumstances will anyone who already holds an advanced degree be permitted to apply for the same degree.

PROVISIONAL CANDIDACY. Under circumstances in which it is difficult to evaluate the academic background of qualified applicants, they may be admitted to *provisional* candidacy. Ordinarily only one semester of study in provisional candidacy is permitted, and the student who fails to qualify for candidacy at the end of that time may be requested to withdraw from the University.

NONCANDIDACY. When staff and facilities are available, the Graduate School will admit some applicants who do not intend to work toward an advanced degree at Cornell but who have special objectives for formal study or scholarly work at the graduate level, provided they satisfy all the entrance requirements expected of degree candidates. Registration in noncandidacy is restricted to two semesters.

CHANGE OF STATUS. A student who wishes to change his status from nondegree candidacy to regular candidacy or from one degree or Field to another, or who, after receiving the Master's degree, wishes to undertake candidacy for the doctorate, must submit to the Dean of the Graduate School a written request giving reasons for the proposed change. Provisional candidacy is automatically reviewed at the end of each semester; therefore, no letter is necessary.

Degree Requirements

THE SPECIAL COMMITTEE. The general degree requirements of the Graduate School are kept at a minimum in order to give the student maximum flexibility in choosing a desirable program of studies. Since progress in graduate study depends so much on the individual student's situation, there are no course or grade requirements imposed by the Graduate School. The student's program is developed with the aid and direction of a Special Committee chosen by the student and is designed to fit his specific needs and desires. Satisfactory progress toward the degree is judged solely by the Special Committee rather than by any arbitrary standards imposed by the Graduate School.

The Special Committee under which a Master of Arts or a Master of Science candidate carries on his work is composed of a chairman who represents the major subject, and one representative of an appropriate minor subject. The Special Committee of a doctoral student is composed of a chairman, representing the major subject, and two other members representing other areas of interest. The chairman of the Special Committee directs the student's thesis research. Some Fields require two minor subjects for doctoral programs while others require only one, but all Ph.D. Special Committees have three members.

The Field and the major subject, as well as the chairman of the Special Committee, are selected by the incoming student. It is his privilege to ask any member of the Graduate School Faculty in the Field of his major subject to serve as his chairman. The chairman in turn advises the student about minor subjects and faculty members who might represent them on his Special Committee. The choice of major and minor subjects and the formation of the Special Committee must be recorded in the Graduate School Office within two weeks of the beginning of residency. Since the student may be uncertain of his aspirations at that time, he is encouraged to change the membership of his Special Committee as his aims become more definite.

In some of the larger graduate Fields the difficulty in making a wise selection of a Committee is so great that the Field Representative or other faculty member may serve temporarily as the chairman while the student seeks a permanent chairman and Committee.

The members of the Special Committee direct the student's program and decide whether he is making satisfactory progress toward the degree. They conduct and report on oral examinations, and they approve the thesis. The Committee and the student constitute an independent working unit. All members of the Graduate School Faculty, however, are free to participate in the scheduled examinations and review the theses of candidates for degrees.

The organization of the Graduate School at Cornell is based on a concept of fields of study independent of colleges and departments. It is thus possible for a graduate student to take courses in any division of the University and to choose major and minor subjects without regard to organizational lines.

RESIDENCE. The Graduate faculty regards study in residence as essential. Although a person working off campus may attain proficiency in a technique or even in a field of knowledge, he may fail in other ways to attain the breadth of knowledge necessary for scholarly work. In addition to contact with the libraries and physical facilities of the University, he needs the daily acquaintance, company, aid, and stimulus of others engaged in similar pursuits. He should form the habit of attending lectures, seminars, and meetings of groups in whose activities he takes interest.

Full-time study for one semester with satisfactory accomplishment constitutes one residence unit. The Graduate School Faculty requires that each candidate for a Master's degree earn two units of residence, and for the Ph.D. degree, six units of residence. However, a longer time is generally required to obtain the degree.

A student must complete all the requirements for the Master's degree in four years and for a doctoral degree in seven years from date of first registration in the Graduate School.

A student in a doctoral program may earn no more than two units, and a student in a Master's program no more than one, for work done in Summer Research, Summer Session, and the Division of Extramural Courses. At least four of the six units required for the Ph.D. degree must be earned as a full-time student, earning three-quarters of a residence unit or more each term, and two of the last four units must be earned in successive terms of full-time study on the Cornell campus.

Transfer of Residence. Candidates for the Master's degree may not count study in other graduate schools as part of their residence. Candidates for the doctorate may be permitted to count study for the Master's degree as equivalent to two residence units if it is relevant to their doctoral program; those who have received training of an exceptional quality and amount may petition for more. No commitment regarding this may be made until after the student has entered into residence and his Special Committee has had opportunity to judge his accomplishments. The residence transferred must not exceed that which would have been earned under similar circumstances at Cornell. Credits for study as an undergraduate or as a special student, even in courses designed primarily or wholly for graduate students, will not be allowed.

Summer Session. To receive residence credit for the Summer Session, the candidate must register in both the Summer Session and the Graduate School and must file a statement of courses satisfactory to his Special Committee. A student may, with his Special Committee's prior approval, earn one-half of a residence unit by completing eight hours or more of credit in the eight-week session, or two-fifths of a unit for six hours or more in the six-week session, but no more than two units in a twelve-month period.

Requirements for Master's degrees may, upon advanced approval of the General Committee, be completed solely during the summer period if instruction in the chosen major and minor subjects is offered. Residence may be transferred for study during one Summer Session preceding matriculation in the Graduate School if this study is an integral part of the graduate program subsequently undertaken, and if the transfer is recommended by the student's Special Committee and approved by the dean of the Graduate School.

Summer Research. To encourage students to continue their studies during the summer period, no tuition or fees are charged for Summer Research if the student has been registered during the previous academic year. Substantial funds are also available for Summer Research assistantship support.

The student has access to the regular services of the University Clinic and Infirmary during the summer with charge if he has been registered as a full-time student during the previous academic term and is registered for Summer Research on a non credit basis. Under certain conditions, students may also accumulate residence credit in Summer Research.

Part-Time Studies. Essentially, all graduate students at Cornell are full-time students. If employment is necessary, students may hold positions requiring up to ten hours of work per week without reduction of residence credit. Teaching fellows and research assistants whose duties require up to twenty hours a week can obtain full residence credit.

Part-time employees are eligible for residence units as follows.

Employment	Residence Units Allowable per Semester		
Total clock hours per week	*Contributory in the major field of study and on campus*	*Noncontributory but on campus*	*Off campus*
0–10 hours	1 unit	1 unit	1 unit
11–20 hours	1 unit	¾ unit	¾ unit
21–30 hours	¾ unit	½ unit	*(See below)*

Those employed for more than twenty clock hours per week off campus, or more than thirty clock hours per week under any circumstances, may earn a maximum of two-fifths of a residence unit per semester through registration in the Division of Extramural Courses, but this will be permitted only on the basis of petition approved prior to the time that the work is undertaken.

Students enrolled in the Division of Extramural Courses are not legally graduate students.

To accumulate residence units for course work completed through the Division of Extramural Courses, fifteen credit hours are the equivalent of one residence unit, and six credit hours the equivalent of two-fifths of a unit—the smallest fraction that will be recorded by the Graduate School toward fulfillment of residence requirements. Detailed information concerning extramural courses and registration procedures may be obtained from the Division of Extramural Courses, B-20 Ives Hall.

EXAMINATIONS. The Special Committee conducts the examinations required for the degree. At the discretion of the Special Committee these examinations may be entirely oral or both oral and written.

For the Master's degree a final examination is required, which under certain conditions may be combined with the admission to (Ph.D.) candidacy examination.

For the doctoral degree: (1) A comprehensive admission to candidacy examination for formal admission to doctoral candidacy is required. This examination may not be taken until two units of residence credit have been accumulated; it must be attempted before the beginning of the student's seventh unit of residence. Two units of residence must be credited after this examination; (2) A final examination, given after completion of the doctoral dissertation and covering subject matter related to the dissertation topic, is also required.

In some Fields a qualifying examination is given at an early date to determine the student's fitness for advanced study and to help the Special Committee plan his program.

In Fields that so desire, the Special Committee may, after the admission to candidacy examination has been taken, nominate the student for a Master's degree without the requirement of a thesis whether or not admission to candidacy for the Ph.D. has been approved. The degree would be awarded after the completion of four units of residence.

FOREIGN LANGUAGE REQUIREMENTS. Each Field has its own foreign language requirements which it considers most useful to the particular area of study. Any Special Committee may, at its discretion, require knowledge of foreign languages beyond the announced requirements.

Candidates required by the Field or their Special Committee to demonstrate reading ability in a foreign language should find out from their Special Committee chairman how the requirement is to be satisfied. The method required is up to the Field or the Special Committee but typically could be a Field-administered examination, a passing grade in a specified language course, a passing score on either the Educational Testing Service Graduate School Foreign Language Tests or the College Entrance Examination Board language tests, or in case of the more unusual languages, an examination given by a faculty member of the Division of Modern Languages.

A student may petition the dean to transfer a language examination taken elsewhere to his record at Cornell.

Courses designed to aid graduate students in learning how to read French, German, Russian, and Spanish are given by the Division of Modern Languages in cooperation with the Graduate School Faculty.

THESIS. Candidates for the degree of Master of Arts or Master of Science are required to submit a thesis in fulfillment of the requirements for the degree (except as stated on p. 12). Some Fields also require a thesis for professional Master's degrees. Candidates for the doctoral degree must complete a thesis which constitutes an imaginative contribution to knowledge. The faculty requires publication of Ph.D. theses by abstract or microfilm.

Financial Support

Extensive financial resources are available to Cornell graduate students to help them defray the cost of their education. Currently, approximately 3,100 of the 3,500 graduate students receive financial aid in the form of fellowships, teaching assistantships, and research assistantships. But the amount of support available from outside the University is contracting sharply, so that the number of students with fellowships or assistantships is expected to decrease.

In most cases the stipends awarded to graduate students are not high enough to cover living expenses completely. A great deal depends on the level of subsistence to which the individual has become accustomed and the sacrifices that he is willing to make for his education. Experience has shown that married students with dependent children have particular financial difficulties. The minimum subsistence income which such students need is about $4,000 plus tuition and the General Fee per academic year. Since stipends are frequently lower than this figure, it may be necessary for the student to find other sources of supplementary income, such as loans, in order to complete his studies.

Since the demands of graduate study are so great, students are discouraged from trying to support themselves by unrelated employment.

No special forms are available for financial aid. The applicant should check the type or types of appointment for which he wishes to be considered on the application for admission form.

TEACHING FELLOWSHIPS. The duties of a teaching fellow normally involve classroom and laboratory instruction of undergraduates and, as such, play a major role in the educational process and the academic atmosphere of the University. Since a large majority of Cornell's graduate students eventually seeks a career in teaching, the experience gained from these appointments is an invaluable part of the student's development. In most Fields students are encouraged to spend some time in teaching, and in some Fields the faculty believe the experience so important that they require it of all students in doctoral programs. An appointment as a teaching fellow is usually in the student's major Field or in one that is closely related. The duties require from ten to twenty total clock hours of the student's time a week, depending on the Field. A teaching fellow whose duties are in his major Field of interest and do not exceed twenty hours is eligible for full residence credit. Salary for a fifteen-hour week will be $2,700 with a slightly higher amount for longer hours, supplemented by a fellowship which covers tuition and the General Fee. Because of possible problems in communication with undergraduates, applicants from non-English-speaking countries are not normally appointed as teaching fellows in their first year at Cornell. Teaching appointments are made by department chairmen. Applications for these positions should be made to the Field Representative of the Field offering the major subject of interest to the student.

RESEARCH ASSISTANTSHIPS. The duties of a research assistant involve work on a research project. The work performed is frequently applicable to the student's thesis research and is under the direction of the chairman of his Special Committee. The student is required to spend twenty hours a week, but if the research is in the Field of his major interest he can earn full-time residence credit. In many Fields of study such appointments are normally made after completion of at least one year of graduate study.

FELLOWSHIPS. A fellowship ordinarily is awarded in open competition to a full-time student who is a candidate for a higher degree (usually a Ph.D.), primarily on the basis of scholastic ability and promise of achievement as a graduate student. The award is made as a tax-exempt gift, and it usually not only covers tuition and the General Fee but also may provide a substantial stipend for living expenses during tenure. Because of the competition for a decreasing amount of funds, the inclusion of financial need criteria is currently under consideration. A student who holds a fellowship is free to select his own research project, subject to the approval of his Special Committee, and his primary responsibility is to pursue his studies for his degree. The award of the fellowship does not obligate the holder to render services to the University, except that in certain fields some teaching is required of all graduate students for the sake of experience and training, nor is the holder of a fellowship committed in any way with respect to future employment. The holder of a fellowship may accept no other appointment or employment without permission of the Cornell Graduate Fellowship Board; however, teaching responsibilities will usually be approved as a routine matter if they contribute to the student's graduate program and do not exceed ten clock hours of work per week.

More than 450 fellowships are under the direct supervision of the Fellowship Board or of academic units of Cornell. The range of stipend (in addition to tuition and the General Fee and, in some cases, dependency allowances) for different categories of fellowships available to first-year students is indicated below.

Cornell Andrew D. White Fellowships—$2,500–$3,000
Cornell Graduate Fellowships—$2,000
Cornell Fellowships from Special Endowments—$1,000–$2,000
Industrial Fellowships—$1,500–$2,500

Many other fellowships are offered to students majoring in certain Fields of study, and some of these are noted in the descriptions of the Fields.

Many private and federally supported fellowships are also administered by the Graduate School. National Science Foundation Traineeships, as well as National Defense Education Act (NDEA) Title IV Fellowships, are available to United States citizens. The application deadline for these is February 1 for the following academic year; candidates for these fellowships are nominated by the Field, having been chosen from among those students applying. NDEA Title IV Fellowships offer three years of support to doctoral students who intend to enter a teaching career. (Since completion of a Ph.D. program at Cornell normally requires four years, and because the program is aimed at prospective teachers, NDEA Fellows are normally expected to gain teaching experience and have support during one of the years as teaching fellows.)

The purpose of the NDEA Title VI (NDFL) Fellowship program is to encourage individuals taking advanced training in languages and in associated area studies designated as being of critical importance to the United States. (For area studies, see pp. 31–40.) Applicants who are interested in NDFL Fellowship support must so indicate when requesting their application materials for admission. National Institutes of Health Traineeships are available and are offered by Fields which have been awarded such grants.

A space is provided on the admission application form in which the student may indicate the type of support for which he wishes to be considered. There is no special fellowship application form.

Prospective graduate students should also consider applying for fellowships awarded on a national basis by the National Science Foundation, the Atomic Energy Commission, the Woodrow Wilson National Fellowship Foundation, and the Ford Foundation. These programs have deadlines for applications, some as early as December 1. Applicants should check on the date pertinent to the fellowship. In some cases it is possible for winners of NSF and AEC awards to hold half-time appointments as teaching fellows for an additional stipend.

New York State provides several forms of financial support. The Herbert H. Lehman Fellowship program is open to applicants from all states whose interests are in social sciences or public or international affairs. These Fellowships are awarded on a competitive basis and may be used only in New York State institutions; they provide each recipient with $4,000 for the first year of graduate study and $5,000 for each subsequent year. New York State residents are eligible for Regents College Teaching Fellowships or Regents Fellowships for Doctoral Study in Arts, Science, and Engineering. Applications for these must be made by December 1 on forms obtained from the Regents Examination and Scholarship Center, New York State Education Department, Albany, New York 12224.

As agreed upon by some of the members of the Council of Graduate Schools in the United States, the regular time for notification of award from Cornell of fellowships and scholarships for the succeeding academic year is April 1. *All fellowship and scholarship applications received by February 1 will be considered for April awards,* and every effort will be made to notify each applicant approved for award no later than April 6 as to whether he has a fellowship or is named as an alternate. It is hoped that the awardees will notify the Graduate School no later than April 15 of their acceptance or rejection of the award; failure to do so will be considered a declination. Applications received after February 1 will be considered only if vacancies occur.

MINORITY GROUP FELLOWSHIPS. Recently the Fellowship Board has awarded a number of fellowships to applicants from minority groups who were not awarded support through the regular channels (regular fellowships, traineeships, teaching and research assistantships, etc.). The student does not apply for these fellowships directly, but is nominated by the Field to which he was admitted if the Field finds that the student cannot be offered support from the other sources mentioned above.

RESIDENCE HALL ASSISTANTSHIPS are available for single or married men and women graduate students in any academic field. These positions are most appropriate for students who desire experience in working with undergraduate students and University staff while contributing financially to their own study.

There are approximately twenty-five resident positions available. Remuneration includes payment of one-half tuition and full fees plus a board supplement and stipend which varies according to responsibilities. Details about the assistantships and application forms may be obtained from the Office of the Dean of Students, 133 Day Hall. A personal interview is required of all applicants. Applications must be completed by February 1, 1971.

PRIZES. Several University prizes are open for competition to all students, including graduate students. The Committee on Prizes of the University faculty publishes an *Announcement of Prize Competitions,* which may be obtained from the Visitor Information Center, Day Hall.

Two prizes are open exclusively to graduate students:

The Guilford Essay Prize. Until at least 1971 a special prize of $120 will be assigned annually to that graduate student who, in the judgment of the Graduate Faculty, writes the best English prose. Each competitor must submit, at or before 4:30 p.m. of the last Monday in November, specimens of his English prose, preferably prepared as a normal part of his training in candidacy for an advanced degree.

The Philosophy Prize. A prize of $50 is awarded to the graduate student who submits the best paper embodying the results of research in the Field of Philosophy. The subject of the paper may be historical or critical or constructive. It may be concerned either with problems of pure philosophy or with the philosophical bearing of the concepts and methods of the sciences. Papers must be submitted on or before the first day of May.

Papers submitted in competition for either prize must be typewritten on bond paper (a clean *ribbon* copy), double-spaced, at least 1,500 and not more than 5,000 words in length, and signed with an assumed name, the real name and address of the competitor being enclosed in a sealed envelope, superscribed with the assumed name. They are to be deposited in the Office of the Graduate School. A student may not submit more than one paper.

LOANS. Applications for National Defense and University loans are available at the Office of Scholarships and Financial Aid, 105 Day Hall.

Increasingly the University is referring both undergraduate and graduate students to their state loan program sponsored under a federal program. Applications for this program can generally be obtained from the student's home bank.

Only graduate students duly registered in a degree-granting program are eligible for loans. Provisional or noncandidate students are not eligible.

The application date for National Defense and University loans is the mid-April prior to the student's September matriculation.

PART-TIME EMPLOYMENT. Opportunities for part-time work are often available in connection with departmental research projects or other activities. Applications for this type of work should be made directly to the department concerned. A candidate may find employment in research or other work closely allied to his academic interest valuable. On the other hand, progress in candidacy is difficult when a student attempts to support himself wholly or partially by work unrelated to his studies. It usually is sounder economy to borrow from the Office of Scholarships and Financial Aid and keep employment to a minimum. However, the University maintains a part-time employment service in that office.

EMPLOYMENT FOR WIVES OF STUDENTS. Cornell University offers many nonacademic positions for working wives through the Personnel Department, B-12 Ives Hall. Types of work include secretarial and clerical work, work for technicians in the various laboratories, library work, limited nursing positions, and some administrative positions. Applications may be made through the Personnel Department upon arrival on campus. Applications for academic positions should apply to the specific departments in which they are interested.

In addition to the University positions, the Ithaca area offers opportunities for similar positions in small industrial plants, at Ithaca College, the local hospital, and various businesses, as well as for teaching positions in the public school system and some professional positions in service agencies. Applicants should go to the New York State Employment Office for further information regarding these opportunities.

General Information

COURSES AND GRADES. The Graduate School is not a course-offering agency. Therefore, students wishing information about courses or grades should inquire at the Office of the Registrar. However, the Graduate Faculty has ruled that a course may not be dropped or changed from credit to audit after the tenth week of classes.

ACTIVITIES FOR GRADUATE STUDENTS. Cornell students enjoy the advantages of a small academic community while having access to many cultural events that rival those of any large city. Lectures, movies, dramatic productions, special art exhibitions, and concerts fill the University's weekly calendar. The Bailey Hall Concert Series brings internationally famous artists and orchestras to Ithaca.

Many graduate students participate with undergraduates in extracurricular activities such as intramural sports, Glee Club, Sage Chapel Choir, publications, music, and folk dancing. A Graduate Student Activities Committee is active in scheduling weekly social events. A Graduate Wives' Club has had a long tradition of activity for the wives of graduate students. Willard Straight Hall and the Sage Graduate Center provide facilities for graduate groups and aid in planning special functions for them.

Cornell United Religious Work (CURW) includes a range of activities for graduate students. Its offices are in Anabel Taylor Hall, which serves as headquarters for chaplains who represent several denominations and who may be consulted by students.

Cornell's location in the Finger Lakes Region of New York State encourages outdoor activity. Many swimming and boating facilities are available. In addition, Cornell operates a private eighteen-hole golf course; indoor and outdoor swimming facilities; an indoor skating rink; tennis, handball, and squash courts; a gymnasium; and riding stables. Several ski resorts also operate nearby.

Many Fields sponsor weekly seminars for their faculty and graduate students.

COUNSELING. The University maintains a variety of counseling services available to graduate students. A student's primary academic counselors are the members of his Special Committee. Other counselors who are able to help in matters of various kinds will be found in the Office of the Dean of Students, the Office of Scholarships and Financial Aid, the International Student Office, the Gannett Medical Clinic, and the Sage Graduate Center.

INTERNATIONAL STUDENTS. Cornell has, since its founding, welcomed students from abroad. Currently about 1,100 foreign students representing ninety countries are pursuing study in a variety of fields.

In addition, each year more than one hundred faculty members spend some time abroad in study and research, often in close association with foreign universities. This creates within the University community opportunities for students from other countries to meet and exchange ideas with members of the Cornell faculty who have firsthand knowledge of several countries and understand and appreciate a variety of cultures.

Special programs within the Graduate School permit study in depth of particular areas such as Africa, Asia, Southeast Asia, Latin America, and the Near East (see p. 31 ff.) Students from these areas have an opportunity to contribute to such programs.

A group of Cornell faculty and Ithaca families maintain a Host Family Program, in which foreign students are invited to share in some aspects of American family life in the Ithaca community. Because the University population is a varied one, the community itself, although not large, tends to have a more cosmopolitan atmosphere than most other small cities, and the student can usually find an outlet for a wide variety of interests. Tours of the community are conducted at the beginning of the fall semester.

The University maintains an International Student Office at 142 Day Hall. Students from abroad are asked to report to this Office upon arriving in Ithaca and are invited to consult the staff on any questions they may have. The Office works in close association with academic advisers and sponsors, and also with persons involved in a number of student and community programs in efforts to enrich the international and cultural life of Cornell.

HEALTH REQUIREMENTS ON ENTRANCE. The following health requirements for entering graduate students have been adopted by the Board of Trustees of Cornell University. The responsibility for fulfilling these requirements rests upon the student; failure to do so may result in loss of the privilege of registering the following term.

Immunization. A satisfactory certificate of immunization against smallpox, on the form supplied by the University, must be submitted before registration. It will be accepted as satisfactory only if it certifies that within the last three years a successful vaccination has been performed. If this requirement cannot be fulfilled by the student's home physician, opportunity for immunization will be offered by the Cornell medical staff during the student's first semester, with the cost to be borne by the student. If a student has been absent from the University for more than three years, immunity will be considered to have lapsed and a certificate of revaccination must be submitted.

The University Health Services strongly recommend that all graduate students be immunized against tetanus before entering the University. Students may, however, obtain initial and all booster tetanus toxoid immunizations at the Gannett Clinic for a nominal charge.

Health History. Graduate students, when accepted, must submit *health histories* on forms supplied by the University. These should be returned promptly to the Gannett Medical Clinic. A University physician will review the material before it becomes part of the student's permanent health record. All information given is confidential. After arrival at Cornell, if the medical history indicates a need, a student will be given an appointment to consult a physician at the Clinic. When a student has been away from the University for more than a year, he must, upon reentrance, submit an interim health history on a University form.

X Ray. Every student is required to have a chest x ray. Opportunity to satisfy this requirement is given during the student's first week on campus. The cost of the x-ray examination is included in the General Fee. When a student who has been away from the University for more than a year wishes to reenter, he must, at his own expense, once more fulfill the chest x-ray requirement.

HEALTH SERVICES AND MEDICAL CARE. Health services and medical care for students are centered in two Cornell facilities: the Gannett Medical Clinic (outpatient department) and the Sage Infirmary.

Students are entitled to unlimited visits at the Clinic. Appointments with individual doctors at the Clinic may be made by calling or going there in person. (An acutely ill student will be seen promptly whether he has an appointment or not.) Students are also entitled to laboratory and x-ray examinations indicated for diagnosis and treatment, hospitalization in the Sage Infirmary with medical care for a maximum of fourteen days each term, and emergency surgical care.

On a voluntary basis, insurance is available to supplement the services provided by the General Fee. For further details see the *Announcement of General Information.* If, in the opinion of the University authorities, the student's health makes it unwise for him to remain in the University, he may be required to withdraw.

If a student prefers to consult a private physician rather than go to the Clinic, or to have the services of a private doctor while a patient in Sage Infirmary, he must bear the cost of these services.

LIVING ARRANGEMENTS. For information about and applications for the University housing described below, write to the Department of Housing and Dining Services, 223 Day Hall.

Dormitory Accommodations. The University has established Sage Graduate Center as a graduate residential center. Its dormitory facilities accommodate approximately 75 men in the north side of the building and 115 women in the south side. The Graduate Center, which is available for use by graduate students and faculty, also contains a cafeteria seating 200, study rooms, and lounges. In addition, Cascadilla Hall has accommodations for approximately 160 men and women.

Family Accommodations. The University has three apartment developments for married students and their families. They are Cornell Quarters, Pleasant Grove Apartments, and Hasbrouck Apartments, with housing for a total of 420 families. All apartments are unfurnished.

Off-Campus Housing. The Department of Housing and Dining also maintains files of voluntarily listed accommodations for use of students and staff members who call at the office. Because the list of available accommodations is constantly changing, it is not practical to mail listings, nor is it feasible to maintain a waiting list of persons seeking accommodations.

MOTOR VEHICLES. The University does not encourage student use of motor vehicles but recognizes that in certain cases there may be important reasons why a student needs a motor vehicle. University regulations apply to all types of motor vehicles, including automobiles, motorcycles, motor bikes, and motor scooters.

Every Cornell University student who owns, maintains, or for his or her own benefit operates a motor vehicle in Tompkins County while the University is in session must register that vehicle with the Board on Traffic Control, unless such vehicle is currently registered with the Board on Traffic Control.

All students required to register motor vehicles must do so within the time designated for academic registration at the beginning of the fall term or the beginning of the Summer Session. Students who enter the University at the beginning of the spring term must register upon entering. Students who reenter the University after a period of absence must register upon reentering. Students who do not own, maintain, or operate motor vehicles which must be registered at one of these times but who later acquire a vehicle or otherwise become subject to registration requirements must complete their vehicle registration within five days after becoming so subject.

The following requirements must be met for vehicle registration:

(1) The applicant must be legally qualified to operate a motor vehicle in New York State.

(2) The vehicle must be registered in New York State or in some other state or jurisdiction that qualifies it for legal operation in the state of New York.

(3) The owner of the vehicle must be covered by effective public liability insurance in the minimum amounts of $10,000–$20,000 for personal injury and $5,000 for property damage. Such insurance must cover any liability incurred while the vehicle is driven either by the registrant or by someone with the registrant's explicit or implicit permission. If at any time such insurance lapses or ceases to be fully effective, the registration of the vehicle shall be automatically cancelled.

(4) There must be no unpaid University-imposed parking fines outstanding against the applicant or the vehicle to be registered.

No vehicle may be parked on the grounds of the University without valid registration and without displaying an appropriate registration and parking permit, as explained in *Regulations Governing Motor Vehicles,* unless the vehicle is not subject to such registration and is parked at a parking meter, parked in a parking area designated for visitors, or has the prior approval of the Board on Traffic Control or its authorized representative.

The student vehicle registration sticker is not a parking permit. Except for those holding parking permits, no student shall park his motor vehicle on the grounds of the University during the hours from 8:00 a.m. to 5:00 p.m. Monday through Friday or from 8:00 a.m. to 1:00 p.m. on Saturdays (except in posted unrestricted time zones and/or unrestricted metered parking spaces).

The student's registration in the University is held to constitute an agreement on his part that he will abide by all its rules and regulations with regard to traffic and parking or suffer the penalty prescribed for any violation of them.

For more detailed information regarding motor vehicle regulations, see the brochure *Regulations Governing Motor Vehicles,* available from the Division of Safety and Security in Barton Hall. Correspondence regarding motor vehicles should be addressed to the Board on Traffic Control, G-2 Barton Hall.

CAREER, SUMMER PLANS, AND PLACEMENT CENTER. The Career, Summer Plans, and Placement Center at 14 East Avenue is a clearing house for jobs in business, industry, government, and teaching, as well as for study programs leading to the professions. It serves as an information center for careers, teacher placement, fellowships, techniques of job hunting, and summer experiences (work, study, travel, service projects). More than a thousand recruiters visit the campus each year representing employers and graduate schools. Students and faculty may keep up to date on the activities of the Center by registering to receive its *Newsletter.* Alumni may be served by either the *Job Bulletin* or the *Registrants Available Bulletin.* Through the support and cooperation of the Cornell Club of New York and the Cornell Society of Engineers, a placement office is maintained in New York City primarily for alumni living in that area.

Tuition and Fees

Tuition and fees* become due when the student registers. Any student who fails to pay his tuition, fees, and other indebtedness to the University at the Treasurer's Office within the prescribed period of grace will be dropped from the University unless the treasurer has granted him an extension of time to complete payment. The treasurer is permitted to grant such an extension when, in his judgment, the circumstances of a particular case warrant his doing so. For any such extension the student is charged a fee of $5. A reinstatement fee of $10 is assessed against any student who is permitted to continue or return to classes after being dropped from the University for default in payments. The assessment may be waived in any instance for reasons satisfactory to the treasurer and the registrar when such reasons are set forth in a written statement.

Students registering at any time during the last ten weeks of any term are required to pay tuition at the rate of 10 percent of the regular tuition of the term for each week or fraction of a week between the day of registration and the last examination day of the term.

Tuition or fees may be changed by the trustees at any time without previous notice.

REGISTRATION DEPOSIT. Every applicant for admission must make a deposit of $35 after receiving notice of acceptance, unless he has previously matriculated as a student at Cornell University. This deposit is used at the time of first registration to pay the matriculation fee, chest x ray, and examination-book charge, and covers certain expenses incidental to graduation if the student receives a degree. The deposit will not be refunded to any candidate who withdraws his application after May 10 or more than fifteen days after his admission approval. This fee is *not* covered by University fellowships, scholarships, or assistantships.

TUITION. Tuition is $200 a term for all students registered in the Graduate School (1) whose major chairman is on the faculty of the statutory division† of the University or (2) who are enrolled in a Master of Arts in Teaching program. Those with major work in the School of Nutrition, the Field of Education, and the Division of Biological Sciences also pay $200 a term. All students in other divisions must pay tuition of $1,010 a term. Tuition is payable at the beginning of each term.

Upon recommendation by the appropriate college dean and by action of the controller, a student who is a teaching or research assistant in one of the statutory schools or colleges may obtain waiver of tuition in the Graduate School if his major field of study is in a statutory school or college.

Assistants in statutory schools or colleges who are on twelve-month appointments and who are registered for Summer Research for credit in the

* All statements in this section are prepared by the University treasurer, who alone is authorized to interpret them.

† The statutory divisions are the Veterinary College, the Colleges of Agriculture and Human Ecology, and the School of Industrial and Labor Relations.

Graduate School may be recommended for waiver of tuition during the summer period under the above limitations. This waiver of tuition does not apply if the student registers in the Summer Session or is not doing productive work for the department.

Any student who is to receive less than full residence credit because of his employment should apply for proration of tuition on forms procurable at the Graduate School Office. *Tuition is based on residence eligibility.* See p. 11.

GENERAL FEE. A fee of $312.50, payable at the beginning of each term, is required of each student registered in the Graduate School whose major chairman is on the faculty of one of the statutory divisions, the School of Nutrition, the Field of Education, or the Division of Biological Sciences. All others pay a fee of $290. This General Fee contributes toward the services supplied by the libraries, Clinic and Infirmary, and the student union in Willard Straight Hall, and pays a portion of the extra cost of laboratory courses and general administration.

A student who is regularly registered in the Graduate School for either one or both terms of the academic year and has paid the above fee is entitled to these services while in residence during the summer immediately following the academic year without payment of an additional General Fee. If such a student registers with the University during the summer, he is liable for payment of any tuition and other fees, and must present his ID card at the time of payment of these charges in order to claim exemption from payment of the General Fee.

A graduate student who returns to the University to present his thesis and to take the final examination for an advanced degree, all other work for that degree having been previously completed, must register as a "Candidate for Degree Only" and pay a fee of $35.

THESIS FEE. Each doctoral candidate must pay $30 when he deposits the approved thesis and abstract in final form. This fee covers the cost of preparing a master microfilm of the entire thesis; of publishing the abstract in the bimonthly periodical *Dissertation Abstracts;* of mailing the microfilm and abstract to the microfilm publisher; and of binding both copies of the thesis for deposit in the University Library.

LIMITED REFUNDS. Part of the tuition and General Fee will be refunded to students who officially withdraw or take a leave of absence during the first nine weeks of a term. A student arranges for a leave of absence or withdrawal at the Graduate School Office. Students who withdraw are charged tuition and the General Fee at the rate of 10 percent for each week or fraction of a week from registration to the effective date of withdrawal. No charge is made if the student begins his leave of absence or withdraws within six days of registration. No part of the registration or matriculation fee is refundable.

SUMMER SESSION. Graduate students who attend classes in the Summer Session must register both in the Graduate School and in the Summer Session; they must pay the tuition and fees listed in the *Announcement of the Summer Session.*

SUMMER RESEARCH. Students registered for Summer Research pay one-half of the General Fee for a registration period of not more than eight weeks and the full fee for a longer registration period unless they were regularly registered in the Graduate School during the previous academic year. For those students eligible for and desiring residence, a prorated tuition is charged in accordance with the fraction of a residence unit to be earned, based on the tuition in effect for the subsequent academic term.

IN ABSENTIA. A graduate student registered *in absentia* will pay a fee of $35 each term.

Advanced Professional Degrees

Advanced professional degrees are designed as preparations and training for a special profession.* The admissions, requirements, and curricula for such degrees, as approved by the Graduate Faculty, are announced by the faculty of a professional school or college, which, for this purpose, acts as a Division of the Graduate Faculty. Degrees are awarded upon recommendation of the Division to the Graduate Faculty. Detailed information regarding admission or academic requirements for any professional degree is included in the *Announcement* of the separate school or college in which the degree is offered. Inquiries addressed to the Graduate School will be forwarded to the proper official. The professional degrees listed below are approved by the Graduate Faculty.

Agriculture

MASTER OF AGRICULTURE (M.Agr.). This degree is intended for professional agriculturists seeking opportunity to study in depth some subject or problem which is pertinent to their profession. Detailed information may be obtained from Director Herbert L. Everett, 192 Roberts Hall.

Architecture, Fine Arts, City and Regional Planning

The following three degrees are administered by the Division of Architecture, Art, and Planning of the Graduate School. Inquiries should be addressed to the listed professor.

* The following are advanced degrees which are also first degrees of a school or college and therefore are not subject to the jurisdiction of the Graduate Faculty. For information regarding them, address the school or college indicated.

Master of Engineering (Aerospace)	Graduate School of Aerospace Engineering
Master of Business Administration Master of Public Administration	Graduate School of Business and Public Administration
Doctor of Law	Law School
Doctor of Medicine	Medical College, New York City
Doctor of Veterinary Medicine	Veterinary College

For more detailed information on these degrees, as well as those in architectural structures, architectural history, and art, see also the *Announcement of the Graduate School: Humanities.*

MASTER OF ARCHITECTURE (M.Arch.). Training in urban design. Only graduates of a five-year professional program in architecture or graduates of a program in city planning or landscape architecture are admitted as candidates. (Professor Colin Rowe.)

MASTER OF FINE ARTS (M.F.A.). Advanced training in the practice of painting, sculpture, or graphic arts. (Professor Jason Seley.)

MASTER OF REGIONAL PLANNING (M.R.P.). Training for a professional career in the field of city planning or regional planning. (Professor Kermit C. Parsons.)

Communication Arts

MASTER OF COMMUNICATION ARTS (M.C.A.). The focus of this program is more on the *strategic application* of communication knowledge and technology than on technical competence in media operation. The curriculum is designed for those students who wish to work with agencies in which organized public communication is a key concern. Emphasis is placed on three key elements: (1) analysis of what is known about the communication process, (2) exploration of the potential of current and new communication techniques and technology, and (3) application of the first two elements to specific communication problems.

Education

Two professional degrees are administered by the Field of Education of the Graduate School. The programs leading to each of the degrees include courses, seminars, projects, and investigations that will develop the student's ability to perform acceptably the professional duties required of the several types of educational specialization.

MASTER OF ARTS IN TEACHING (M.A.T.). This program is designed for and limited to those preparing for teaching the following subjects only in secondary schools: agriculture, biology, chemistry, earth science, English, French, home economics, physics, and social studies. The student and his Special Committee will select those courses and seminars in his teaching specialty and in education which are deemed most appropriate for developing competence as a teacher. The student will be required to demonstrate his teaching skill in a supervised field experience. Completion of two regular semesters and one summer of full-time study, or two and two-fifths residence units is required. Graduates of a teacher-training program are not eligible for this degree.

DOCTOR OF EDUCATION (Ed.D.). The program for this degree is designed to prepare the candidate within a broad cultural context for positions of professional leadership in education. The program of studies must include advanced work in each of the following: educational psychology, history or philosophy of education, educational measurement and statistics, and research in education. At least fifteen hours of credit must be earned in courses other than those in professional education. A minimum of sixty-five credit hours beyond the Bachelor's degree is required, of which thirty-five hours should be completed beyond the Master's degree or its equivalent. A candidate is required to complete a minimum of five residence units beyond the Bachelor's degree and a year of directed field experience.

Professional Teaching

MASTER OF SCIENCE FOR TEACHERS (M.S.T.). This is a coordinated program of training in the biological and physical sciences for practicing teachers. Each degree candidate must satisfy a broad core program in mathematics and science and complete advanced work in his selected field of study. This degree is administered by the Division of Professional Teaching of the Graduate School. Detailed information may be obtained from the Graduate School Office, Sage Graduate Center.

Engineering

MASTER OF ENGINEERING. The Master of Engineering degree is administered by the Engineering Division of the Graduate School. Specially oriented graduate programs of study are in the areas of agricultural, chemical, civil, electrical, industrial, materials, mechanical, and nuclear engineering, and in engineering physics. The following titles designate the professional Master's degrees offered in engineering: Master of Engineering (Agricultural), Master of Engineering (Chemical), Master of Engineering (Civil), Master of Engineering (Electrical), Master of Engineering (Engineering Physics), Master of Engineering (Industrial), Master of Engineering (Materials), Master of Engineering (Mechanical), Master of Engineering (Nuclear). The Graduate School of Aerospace Engineering administers the Master of Engineering (Aerospace) degree program.

The general requirements for the degrees listed above are:

1. A minimum of thirty credit hours of advanced technical course work in the specific field or in related subjects.

2. A minimum of three credit hours (included in the above) of engineering design experience involving individual effort and formal report.

3. A minimum grade point average of 2.5 and a minimum final grade of C minus for all courses counting toward the degree.

There are no residence requirements, although all course work must, in general, be completed under Cornell University staff instruction. The degree requirements must normally be completed within a period of four calendar years.

Graduates of Cornell University who hold Bachelor of Engineering degrees may be granted up to fifteen hours credit for advanced courses taken during their fifth undergraduate year, provided they enter the Master of Engineering program not later than the fall term following the sixth anniversary of their receiving the Bachelor of Engineering degree.

The *Announcement of the College of Engineering* should be consulted for further details on the various professional Master's programs.

English

MASTER OF FINE ARTS (M.F.A.). The degree of Master of Fine Arts in creative writing is designed to prepare candidates for careers in professional writing or in the teaching of creative writing. The program is administered by a specially appointed committee of the Department of English, acting as a Division of the Graduate School.

Industrial and Labor Relations

MASTER OF INDUSTRIAL AND LABOR RELATIONS (M.I.L.R.). The four-semester program leading to this degree provides a basic course of graduate study for those with professional interests in industrial and labor relations and further provides limited opportunities for specialized professional study where broad competence has been established. This degree is administered by the Division of Industrial and Labor Relations of the Graduate School. Students possessing a law degree may be eligible for a two-semester M.I.L.R. program. More information may be obtained by writing to: Graduate Field Representative, School of Industrial and Labor Relations, Ives Hall.

Law

The following two degrees are administered by the Division of Law of the Graduate School. The *Announcement of the Law School* should be consulted for a complete description of the program and requirements.

MASTER OF LAWS (LL.M.). This degree is intended primarily for the student who desires to increase his knowledge of the law by working in a specialized field.

DOCTOR OF THE SCIENCE OF LAWS (J.S.D.). This degree is intended primarily for the student who desires to become a proficient scholar by original investigation into the functions, administration, history, and progress of law.

Music

The following two degrees are appropriate for mature composers who seek further professional training as well as knowledge of the other arts and humanities, both to enrich their creative perspectives and to prepare them for the teaching of composition and theory at the university level.

MASTER OF FINE ARTS (M.F.A.)

DOCTOR OF MUSICAL ARTS (D.M.A.)

These degrees are administered by the Department of Music, acting as a Division of the Graduate School for this purpose. More information may be obtained from Professor Robert M. Palmer, 218 Lincoln Hall.

Nutritional and Food Science

The following two degrees are administered by the faculty of the Graduate School of Nutrition acting as a Division of the Graduate School. More information may be obtained by writing to: Secretary, Graduate School of Nutrition, Savage Hall.

MASTER OF NUTRITIONAL SCIENCE (M.N.S.). This program emphasizes fundamental study in the basic biological sciences that can lead to specialization in such areas as nutritional biochemistry, human and clinical nutrition, experimental or animal nutrition, and public health and international nutrition. The program is open to students who have had no previous course work in nutrition. For candidates interested in the biological sciences, the program serves as a valuable preliminary for graduate study for the Ph.D. degree in such areas as biochemistry and physiology, as well as human or animal nutrition.

MASTER OF FOOD SCIENCE (M.F.S.). The fundamental sciences, chemistry, biochemistry, and bacteriology, that are involved in food processing and utilization, are emphasized. Electives are available to meet individual needs in engineering, economics, marketing, business administration, and international programs. The specialized training serves as a preparation for technical work in the food industry or for more advanced graduate study.

The *Announcement of the Graduate School of Nutrition* should be consulted for further details on the professional Master's degree programs.

Theatre Arts

MASTER OF FINE ARTS (M.F.A.). The degree of Master of Fine Arts in theatre arts is intended for students who wish to increase their professional competence as actors or directors through a studio-oriented program. It is administered by the Department of Theatre Arts, acting as a Division of the Graduate School for this purpose.

Veterinary Medicine

DOCTOR OF SCIENCE IN VETERINARY MEDICINE (D.Sc. in V.M.). This degree is characterized by a professional rather than a general research objective, and it is designed especially for experienced persons in the basic and clinical sciences who need more specific, advanced, scientific, and professional knowledge in order to equip themselves for careers in teaching and research. This degree is administered by the Division of Veterinary Medicine of the Graduate School.

Graduate School of Medical Sciences

The opportunity for graduate work leading to advanced general degrees was first offered in the Medical College in 1912 in cooperation with the Graduate School of Cornell University. In June 1950, the trustees of Cornell University entered into an agreement with the Sloan-Kettering Institute for Cancer Research whereby a new division of the Medical College, namely, the Sloan-Kettering Division, was created for the purpose of offering additional opportunities for graduate study toward advanced degrees, thus extending the areas of the basic sciences.

That expansion of the New York City component of the Graduate School resulted in the establishment, in January 1952, of the Graduate School of Medical Sciences which, with the approval of the Faculty of the Graduate School of Cornell University, was given the full responsibility for administrative matters related to the advanced general degrees granted for study in residence at the New York City campus of Cornell University.

DEGREES. The general degrees of Ph.D. and M.S. are awarded for advanced study and scholarly, independent research in the fields of anatomy, biochemistry, biomathematics, biophysics, biostatistics, cell biology, genetics, microbiology, neurobiology and behavior, pharmacology, and physiology.

FACILITIES. The facilities for graduate work at the Graduate School of Medical Sciences include those of the Medical College and of the Sloan-Kettering Division. The five buildings of the Medical College, extending along York Avenue from Sixty-eighth to Seventieth Street in New York City, contain the lecture rooms, student laboratories, library, and research facilities for graduate and undergraduate work. The Sloan-Kettering Division is located in the Sloan-Kettering Institute and the Kettering Laboratory on East Sixty-eighth Street in New York City, and in the Walker Laboratory in Rye, New York. The special facilities and experienced investigators of the Sloan-Kettering Division offer ample opportunity for advanced graduate work in the basic science aspects of research related to cancer and allied diseases.

FINANCIAL ASSISTANCE. Predoctoral fellowships are available to qualified applicants. The fellowships may be renewed yearly providing the academic performance of the fellowship holders is satisfactory. Teaching fellowships and research assistantships are available to qualified graduate students in some departments of the Medical College. In addition to a stipend, the costs of tuition and fees are defrayed for those students receiving financial assistance.

FURTHER INFORMATION. Information on financial assistance and the entire program of the Graduate School of Medical Sciences is provided in the *Announcement of the Graduate School of Medical Sciences.* Requests for that *Announcement* should be addressed to the Graduate School of Medical Sciences, Cornell University, Medical College, 1300 York Avenue, New York, New York 10021.

Special Resources for Research and Advanced Study

The descriptions below are limited to major general facilities available to graduate students. Other substantial collections and facilities, in many instances unique, have been assembled for the use of graduate students. Although the facilities cannot be described adequately in this *Announcement,* some of them are mentioned in the statements given under the Fields of Instruction on p. 50 ff.

Cornell University Libraries

The libraries are among the principal facilities in the University's program of graduate studies. The total number of volumes at Cornell is now over 3,600,000 and that figure increases by about 200,000 each year. For the convenience of students and faculty, the holdings are organized into a controlled system of distinct libraries. Some of the libraries are large; some have limited holdings. Some are general; some selective. Each library, whether within one of the colleges or housed in a building of its own, is situated where its books and its facilities lie most easily available to those who use them most. The libraries, whatever their nature, have been developed over many years by scholarly librarians and professors with the view of achieving breadth and depth in the central libraries, utility and coherence in the specialized ones.

The University's libraries offer support for graduate studies at several levels. They provide basic readings in virtually all subjects, collateral studies for classroom and seminar instruction, and highly specialized materials for advanced students. An unusually rich collection of reference works, both modern and antiquarian, expedites both daily study and dissertational research. Of journals and periodicals, about 50,000 titles are available, most of them in complete runs, some of them in multiple copies, all of them immediately available. Special departments are maintained for maps, microtexts, documents, newspapers, and other such collections.

To most graduate students, Olin Library, designed primarily as a research library, becomes the most familiar. Olin Library, completed in 1961, offers every modern library facility for its readers. The building is completely air-conditioned, scientifically lighted, comfortably furnished, and organized for efficient operation. It provides easy access to the book stacks, convenient photocopying facilities, and a comfortable lounge area for graduate students. Congestion is eliminated not only because of architectural design but also because undergraduates have their own open-stack library in a separate building. A graduate student whose work has advanced to the writing stage may apply for use of a carrel adjoining the book stacks in order to facilitate completion of his dissertation. Olin Library is open during the term from 8:00 a.m. to 12:00 midnight weekdays, and from 1:00 p.m. to 12:00 midnight Sundays.

Within Olin are a number of special collections likely to be of particular interest to advanced students of the social sciences and the humanities. The Department of Rare Books houses several distinguished collections, among them books and manuscripts relating to Dante, Petrarch, Wordsworth, Joyce, Shaw, and other literary figures. The Noyes Collection is rich in American historical documents, especially those pertaining to Lincoln and the Civil War. Students in the social sciences will also find extraordinarily interesting manuscripts and books in the collections of slavery and abolition, of witchcraft, of the French Revolution, and of the life and times of Lafayette. Long familiar to professional scholars are the Wason Collection on China, Japan, and Southeast Asia, and the Old Icelandic Collection. The History of Science Collections include the Adelmann Library of Embryology and Anatomy, and the library of the French scientist, Lavoisier. The Collection of Regional History and Cornell University Archives is a manuscript depository with total holdings of more than 20,000,000 items. These manuscripts relate to all aspects of the economic, political, and social history of this region and the areas historically connected with it. Here, too, are the documents and manuscripts relevant to the founding and development of Cornell University. In addition to the collections in Olin Library, many of the college and department libraries also contain materials unique in their respective fields. Curators and reference librarians in all the libraries are available for counsel concerning the availability and use of research materials.

The University libraries in aggregate consist of Olin Library, as mentioned, Uris Library for undergraduates, the Physical Sciences Library, the Mann Library of Agriculture and Human Ecology, and the libraries of the following colleges and schools: Fine Arts, Business and Public Administration, Engineering, Hotel Administration, Industrial and Labor Relations, Law, Medicine (in New York City), and Veterinary Medicine. Added to these are the libraries of academic divisions and departments, together with those of the Agricultural Experiment Station at Geneva, New York.

International Studies Programs

Center for International Studies

The primary function of the Center for International Studies is to foster, coordinate, and support the University's international activities. In addition to its role as a link between the activities of the specialized programs, the Center routinely crosses interdisciplinary lines in its endeavor to interest faculty and students in innovative international teaching and problem-centered research.

Students interested in foreign area studies or in international problems will find that the flexibility of both undergraduate and graduate requirements permits considerable latitude in selecting subjects. Appropriate courses of study can be selected from the regular offerings of various departments of the University. For example, in the College of Arts and Sciences the Department of Government offers instruction in comparative government, international relations, and international law and organization; in the Department of Economics there are offerings in international economics, economic development, international trade, and the economics of workers' management; the Department of Sociology offers courses in population problems and international urbanization. In the College of Agriculture courses are available in the economics of agricultural development, international agriculture, and rural sociology. The School of Business and Public Administration offers courses in international development and comparative administration. The School of Industrial and Labor Relations offers courses in international and comparative labor relations.

The graduate student seeking specialized foreign-area knowledge may arrange a minor in one of the interdisciplinary area programs: Asian Studies or Latin American Studies. It is also possible to pursue an area interest in European Studies, Soviet Studies, or African Studies.

In cooperation with the Program on Science, Technology, and Society (STS), the Center is developing a Peace Studies Program. The core of this Program is an interdisciplinary seminar, "The Impact of Technology on Foreign Defense and Disarmament Policies," complemented by several other courses on defense and arms control.

Another area being developed jointly by the Center and STS is international flows of scientific information and manpower. Two new courses have been designed to explore this phenomenon. One deals with flows between developed and developing countries; the other concentrates on scientific/technological flows among developed countries.

A new doctoral specialization in the economics of participation and labor managed systems is offered as part of an interdisciplinary teaching and research program on the problem of participative management.

The International Population Program is being expanded to include the policy, administration, and communications problems related to the development of family planning programs in an international and comparative perspective.

Other activities of the Center include lectures and seminars presented by distinguished visitors, overseas and domestic research projects, conferences, student training, and publication.

The continued growth of the international programs has been accompanied by the creation of an outstanding and comprehensive infrastructure of staff, library, language facilities, and other necessary resources.

The work of the Center and of associated programs and activities is more fully described in the Center's *Annual Report of International Studies at Cornell University.* Further information may be obtained from the Center's office in 217 Rand Hall.

China Program

FACULTY: Knight Biggerstaff, Nicholas C. Bodman, Nai-Ruenn Chen, Chuen-tang Chow, John C. H. Fei, Ta-Chung Liu, John McCoy, David Mozingo, Charles A. Peterson, Harold Shadick, Judith M. Treistman, Martie W. Young.

The China Program provides comprehensive graduate-level training and sponsors a wide range of research. The faculty represent the following fields:

anthropology, economics, government, history, history of art, linguistics, and literature.

Graduate students in the program take a major in one of the fields listed above. They are expected at an early stage to attain sufficient mastery of the Chinese language to permit use of Chinese sources in their courses and seminars and in their research.

The focus of much of the research and teaching in the Program is the society, polity, economy, culture, and arts of modern and contemporary China. Students with this concentration are also expected to develop a general knowledge of traditional institutions and culture. Students majoring in history concentrate on medieval or modern China; no chronological limits apply to those in the history of art, linguistics, or literature.

The China Program supports three projects: political organization, social change, and personality development; economic development within a Chinese cultural setting; and linguistic studies in Southeast China and in the southwest border regions. Research Assistantships are available to advanced graduate students working in these areas, and occasionally in other fields as well. London-Cornell Studentships are open to advanced Ph.D. candidates in the social sciences and humanities who are in the China Program. They are tenable for study during an academic year at the London School of Economics and Political Science or at the School of Oriental and African Studies of the University of London. Stipends include air fares and tuition and fees.

London-Cornell Field Research Grants are open to Ph.D. candidates whose interests directly concern problems of social change in East Asia. Grantees may conduct dissertation research in any part of East Asia, and stipends for this purpose include travel and research expenses.

National Defense Foreign Language Fellowships and Foreign Area Training Fellowships are tenable in the Program. Graduate students may also apply for other assistantships, fellowships, and scholarships offered by the University and its departments.

Additional information on the Program and the various fellowships and awards may be obtained by writing to the Director, China Program, 100-A Franklin Hall.

Program on Comparative Economic Development

The Program on Comparative Economic Development at Cornell University was founded in 1966 by a group of economists in the Department of Economics, the Department of Agricultural Economics, and the School of Industrial and Labor Relations. Its primary purpose is theoretical and empirical research into the causes and forces of economic development, emphasis being placed on the multiplicity and diversity of forms of the development phenomenon.

Several secondary benefits derive, or are expected to derive, from the activities of the Program. One is the educational feedback in the form of seminars, guest lecturers, and the availability of research scholarships to graduate students in the Department of Economics. Further arrangements are being made for the establishment of regional research and educational centers in selected focal development countries.

The Program is not restricted to economists. On the contrary, it is hoped that as time goes on cooperation will be obtained from other fields. In fact, the philosophy of a wider basis of development science, not restricted to economics, is intended to become the central strength of the Program.

Additional information may be obtained by writing to Jaroslav Vanek, Director of the Program, Goldwin Smith Hall.

International Agricultural Development Program

Cornell University provides unusual scope and facilities for graduate-level study and research concerning development of the critical agricultural sector of newly developing nations. An integrated program of research and graduate training is available in the various biological, physical, and social sciences fields which are relevant to agricultural development.

A student preparing for work in international agricultural development majors in a specific Field. In addition to basic preparation in that Field, he may minor in the Field of International Agricultural Development. The student may take courses which help him in applying his knowledge to the special conditions of newly developing nations, consult with experienced faculty members in regard to such application, and pursue a research project for his dissertation which is relevant to the special problems of newly developing countries. In much of this work the program in agriculture draws upon the strong international programs in other colleges of the University, including the area study programs and the varied offerings in modern languages.

Faculty experience in overseas work is continuously developed through work in College of Agriculture overseas programs and individual consulting assignments. Several faculty members, who devote themselves full time to research and teaching in international agricultural development, have built special programs of research and continuing contact with particular geographic areas. The environment for the International Agricultural Development Program is further enhanced by more than 250 foreign graduate students majoring in the various fields of studies represented by the College of Agriculture.

Substantial expansion has recently taken place in the international program of several departments. Most departments have a number of assistantships and teaching fellowships designed to finance graduate students while they work closely with the teaching and research program in international agricultural development. Doctoral candidates in these departments who are interested in international agricultural development generally do field research in newly developing countries for their doctoral dissertations.

Additional information may be obtained by writing to Professor K. L. Turk, Director, International Agricultural Development Program, 102 Roberts Hall.

International Legal Studies Program

The Cornell Law School offers a program of concentrated study in international legal subjects. The full program is ordinarily pursued by J.D. candidates in their second and third years of regular law study, but all the courses in the Field are open to graduate students in law. Some of the courses are offered by visiting faculty members who come to the Law School under its program for distinguished foreign professors. A number of foreign scholars and students also come to Cornell for research and study in the comparative and international law fields. Other activities of the International Legal Studies Program have included faculty seminars in comparative law, summer conferences in public international law, and a program of speakers and seminars open to students. In addition, the Law School sponsors a small number of fellowships for foreign students to pursue graduate work in law.

For more detailed information, see the current *Announcement of the Law School,* and the current *Annual Report of the Center for International Studies.* Further information may be obtained by writing to Professor Robert A. Anthony, Chairman, Graduate Study Committee, Cornell Law School, or to the Director, Center for International Studies, 217 Rand Hall.

Latin American Studies Program

FACULTY: Donald K. Freebairn, director; Frederick B. Agard, Solon Barraclough, Jerome S. Bernstein, Dalai Brenes, Loy V. Crowder, David Davidson, Tom E. Davis, Martin Dominguez, Matthew Drosdoff, Charles L. Eastlack, Rose K. Goldsen, Thomas Gregor, Joseph A. Kahl, Eldon Kenworthy, Anthony G. Lozano, Thomas F. Lynch, Robert E. McDowell, James O. Morris, John V. Murra, Thomas Poleman, Glenn F. Read, Bernard Rosen, Donald F. Solá, J. Mayone Stycos, H. David Thurston, William F. Whyte, Lawrence K. Williams, Frank W. Young.

The Latin American Studies Program enables the graduate student to develop specialized competence in the history, culture, social organization, and languages of Latin American countries. The student majoring in a relevant discipline can minor in Latin American Studies.

Some forty courses directly pertaining to Latin America are offered by the Departments of Agricultural Economics, Agronomy, Animal Science, Anthropology, Consumer Economics and Public Policy, Development Sociology, Economics, Government, History, History of Art, Industrial and Labor Relations, Romance Studies, and Sociology. The courses constitute the basis for formulating programs leading to a graduate *minor* in Latin American Studies. Normally, five or six semester-long offerings satisfy the formal course requirements. In addition, the degree candidate minoring in Latin American Studies must exhibit proficiency in reading and speaking either Spanish or Portuguese.

Applications for scholarships, fellowships, or teaching fellowships should be made to the department in which the student is taking his major. Students minoring in Latin American Studies qualify for NDEA Title VI Modern Language Fellowships. Application forms may be obtained from the Graduate School.

Summer research travel grants and support for on-campus course work during the summer are available to selected graduate students through the Latin American Studies Program. Although thesis research may be supported by the Program, support should first be sought from the Foreign Area Training Fellowship Program, the Social Science Research Council, Fulbright-Hays, the Doherty Foundation, and the Organization of American States.

Because of the considerable volume of research on Latin America currently being carried out by Cornell faculty members, students will normally be afforded the opportunity of participating in ongoing projects while in residence and will generally be expected to do field work in Latin America at some stage of their graduate training. Major research projects are under way in the fields of Andean community development, comparative economic development, fertility and population, descriptive linguistics, and urbanization.

Additional information may be obtained by writing to Donald K. Freebairn, Director, Latin American Studies Program, Rand Hall.

South Asia Program

(Bhutan, Ceylon, India, Nepal, Pakistan, Sikkim)

STAFF: Gerald Kelley, director; Messrs. Douglas E. Ashford, Harold R. Capener, Arch T. Dotson, Harold Feldman, James Gair, Leighton W. Hazlehurst, Michael Hugo-Brunt, Kenneth A. R. Kennedy, John W. Mellor, Stanley J. O'Connor.

The increasing importance of the peoples of the Indian subcontinent and of the role they play in world affairs enhances the need for providing opportunities in America for training and research in the field of Indic studies. The South Asia Program at Cornell, dealing primarily with India, Pakistan, Ceylon, and Nepal, is organized and equipped to help meet this need. Since 1948 it has sponsored a series of research projects on India and Ceylon, and it has trained a distinguished group of younger American and South Asian scholars in South Asian area and language studies. The Program faculty includes members from agricultural economics, anthropology, government, history of art, human development and family studies, business and public administration, development sociology, city and regional planning, and languages and linguistics. Sanskrit, Pali, Hindi, Urdu, Telugu, and Sinhalese are languages regularly offered at Cornell. Cornell participates in the interuniversity summer program which provides instruction in other South Asian languages and selected social sciences and humanities disciplines each summer on the campus of a member eastern university.

Qualified graduate students interested in specializing in the study of South Asia minor in Asian Studies with concentration on South Asia, in South Asian art history, or in South Asian linguistics. The doctoral candidate must have a reading knowledge of Hindi or, depending upon the subarea of his specialization, some other important language of South Asia.

RESEARCH AND FIELD TRAINING. The doctoral dissertations of students in the South Asia Program are normally based on research done in India, Pakistan, Ceylon, or Nepal. Students' field research may benefit from advice and guidance in the field by a Program staff member. At least one member of the faculty of the South Asia Program has been in South Asia for each of the last several years. Cornell is a charter member of the American

Institute of Indian Studies, which was organized to facilitate study and research in India by American advanced students and by faculty specializing in various aspects of Indian civilization and contemporary affairs. The University also maintains close links with a number of research agencies, programs, and institutions of higher learning, such as the Deccan College Postgraduate Research Centre, Delhi University, Osmania University (Hyderabad), and universities in Ceylon. Staff members of these institutions have provided valuable assistance to Cornell students working in India. There are opportunities for graduate students to become associated with Cornell-sponsored research in South Asia or to carry on independent research abroad. Every effort is made by the Program staff to aid qualified students to obtain financial support for a field training or research project in one of the countries of the area.

Research interests under the South Asia Program are focused largely on recent or contemporary developmental problems of the countries of the area—on changes taking place in the economic, political, social, religious, artistic, and intellectual life of the region. A long-term research project in progress in India is primarily concerned with the ramifying problems of introducing technological changes and the influence of such changes when adopted. Since 1949 faculty and students in anthropology have carried on an extended and varied series of rural and urban community studies in several different regions of India from the Deccan into the Himalayan foothills. A major related project, the Cornell International Agricultural Development Program, which is supported by Ford Foundation funds, is concerned with the development of the entire agricultural sector of the Indian economy. With Ford Foundation support, Cornell is assisting Delhi University to become a major center in the field of linguistics. At the same time, other studies in urban renewal and regional planning, public administration, the role of government in cultural change, and recent movements in the arts and in religions and ideologies are in progress under faculty direction. Cornell is also making a special study of the Sinhalese language and of linguistic problems of Ceylon. Research is also under way on Oriya and Telugu, important regional languages of India. The new nations of South Asia present so many problems for study that the areas of inquiry open to students and staff members are limited only by availability of research means.

FELLOWSHIPS AND ASSISTANTSHIPS. Fellowship and assistantship awards are available to qualified graduate students minoring in Asian Studies with a concentration on South Asia. The South Asia Program fellowships are open to incoming graduate students with South Asia interests and should be applied for by writing to: Director, South Asia Program, 221 Morrill Hall. These fellowships are normally given to provide supplementary support for student research projects, at Cornell or in the field. Students in the South Asia Program are also eligible for assistantships in their major discipline departments, for fellowships and scholarships offered by the Cornell Graduate School, for National Defense Foreign Language Fellowships, and for Foreign Area Training Fellowships. Additional information on financial aid may be obtained by writing to the director, at the address given above.

Southeast Asia Program

FACULTY: Benedict R. Anderson, Arch T. Dotson, John M. Echols, Frank H. Golay, Alexander B. Griswold, Robert B. Jones, Jr., George McT. Kahin, Stanley J. O'Connor, Robert A. Poison, Robert M. Quinn, Lauriston Sharp, James T. Siegel, John U. Wolff, O. W. Wolters.

The Southeast Asia Program possesses substantial facilities for study and research on the graduate level and provides exceptional opportunities for general or specialized work on all of Southeast Asia in various disciplines of the humanities, social sciences, and some natural sciences, as well as in interdisciplinary area seminars. Instruction in the major languages of the area is an integral part of the graduate training of the Southeast Asia Program. Much basic and pioneering research remains to be done in this area, and the Southeast Asia Program is organized and equipped to help meet such needs.

Special intensive instruction in Southeast Asian languages is available during summer sessions. Entering graduate students intending to study one of these languages are encouraged to begin such study during the summer preceding registration in the Graduate School. Inquiries should be made as early as possible to the director of the Southeast Asia Program.

Southeast Asia Program fellowships are available on a competitive basis to graduate students. They carry stipends of up to $3,200 plus tuition and General Fee, and are available only to qualified candidates for advanced degrees at Cornell. Competition for these awards is open to citizens of the United States or Canada, nationals of Southeast Asian countries, and, in exceptional cases, nationals of other countries.

The fellowships are available to applicants who are able to demonstrate a serious scholarly interest in Southeast Asian studies; who show the greatest promise of becoming qualified regional experts with specialization in a relevant discipline of the humanities, social sciences, or certain natural sciences; and who are admitted to the Cornell Graduate School for advanced work in such a discipline. Previous experience in Southeast Asia or in the study of that area is not necessarily required. It is important that the applicant be able to show that advanced work in a major subject offered at Cornell, combined with work in the Southeast Asia Program, will make his future professional activities more effective; this requirement is particularly important for a student in the natural sciences.

Fellowships are normally awarded for one academic year. If the student's work during the first year has been of high caliber, reappointment is sometimes possible. In such cases, formal reapplication is expected from the student. The primary purpose of these awards is to encourage graduate students to acquire a substantial knowledge of Southeast Asia while majoring in one of the discipline Fields of the Graduate School. Accordingly, they are usually offered only to students who take a minor in Asian Studies and participate fully in the Southeast Asia Program. The recipient of a fellowship may be asked to devote up to six hours a week under faculty supervision to work connected with the Program.

London-Corneli Studentships are available for advanced Ph.D. candidates in the social sciences and the humanities who have already had at least one year of resident study in the Southeast Asia Program. These fellowships are tenable for study during an academic year at the School of Economics and Political Science or the School of Oriental and African Studies in the University of London. Stipends range up to $3,000 plus air fares and tuition and fees. London-Cornell Field Research Grants are open to Southeast Asia Program Ph.D. candidates in the social sciences and humanities after they have had appropriate training at Cornell, or at Cornell and London. They are tenable for up to twenty-two months for the purpose of dissertation research in any part of Southeast Asia. Stipends range up to $12,000 for twenty-two months including travel and research expenses.

Cornell-Philippines Field Research Fellowships are available, under a grant from the Rockefeller Foundation, for advanced graduate students who plan to write dissertations in the social sciences or the humanities, based upon field research in the Philippines. Fellowship support is for ten to fifteen months in the Philippines and includes living costs, local transport, and round-trip transportation from the United States for the graduate student and dependent wife or husband.

National Defense Foreign Language Fellowships, Title VI, are offered by the United States Office of Education for study during the academic year, the summer, or both. Application should be made to Sage Graduate Center, Cornell University. Information about Foreign Area Training Fellowships, administered by the Social Science Research Council, may be obtained by writing to the Foreign Area Fellowships Program, 444 Madison Avenue, New York, New York 10022. Graduate students may also apply for other fellowships, teaching fellowships, assistantships, and scholarships offered by the University and its departments.

Additional information on the Program and the various fellowships and awards may be obtained by writing to the Director, Southeast Asia Program, 108 Franklin Hall.

Soviet Studies

COMMITTEE ON SOVIET STUDIES: George Gibian, chairman; Urie Bronfenbrenner, M. Gardner Clark, Walter Galenson, Richard Leed, Walter Pintner, Myron Rush, George Staller.

OTHER FACULTY MEMBERS IN SOVIET STUDIES: Patricia Carden, Frederick Foos, Antonia Glasse, Boris Glasse, Augusta Jaryc, Alla Novosilzova, Hugh Olmstead, Marla Wykoff.

The University offers a number of courses and seminars on the Soviet Union as well as pre-1917 Russia. Instead of a separate area program, graduate students have a choice of majors and minors in the established Fields of the Graduate School. Some of the subjects focus on area specialization: Russian history, Russian literature, Slavic linguistics. Other subjects combine area specialization with a nonarea framework: comparative government, economic planning, regional planning, social psychology.

Graduate students pursuing Soviet Studies in any of these subjects are expected to attain proficiency in the Russian language either before entering the Graduate School or soon thereafter.

The University's academic activities related to Russia are coordinated by the Committee on Soviet Studies. The Committee also sponsors a colloquium for faculty members and graduate students in Soviet Studies. In the Soviet Studies Graduate Study in the John M. Olin Library, major reference works and key current periodicals from and about the U.S.S.R. are brought together.

The Committee on Soviet Studies selects a limited number of graduate students each year as research assistants. The Russian section of the Division of Modern Languages and the Department of Russian Literature also appoint several graduate students annually as teaching fellows in the Russian language. For other teaching fellowships, fellowships and scholarships, students apply directly to the Graduate School or to the department concerned. NDEA Title IV and Title VI Fellowships are available in various subjects.

A list of faculty specialization follows: *Economics:* M. Gardner Clark, Walter Galenson, George J. Staller; *History:* Walter M. Pintner; *Languages and Linguistics:* Frederick Foos, Boris Glasse, Richard Leed, Augusta Jaryc, Alla Novosilzova, Hugh Olmstead, Marla Wykoff; *Literature:* Patricia Carden, George Gibian, Antonia Glasse, Hugh Olmsted; *Political Science:* Myron Rush; *Psychology:* Urie Bronfenbrenner.

Inquiries about fellowships and other aspects of Soviet Studies should be addressed to Professor George Gibian, Chairman, Committee on Soviet Studies, Goldwin Smith Hall.

Other Programs and Studies

American Studies

COMMITTEE ON AMERICAN STUDIES: S. Cushing Strout, chairman; Archie R. Ammons, LeGrace G. Benson, Jonathan P. Bishop, Douglas F. Dowd, Robert H. Elias, Robert T. Farrell, Heywood Fleisig, Paul W. Gates, Rose K. Goldsen, Andrew Hacker, Baxter L. Hathaway, Richard I. Hofferbert, Michael G. Kammen, Michael Kaufman, Walter LaFeber, Thomas W. Leavitt, John E. Martin, James H. Matlack, Dan E. McCall, James R. McConkey, Andrew J. Milnor, Arthur M. Mizener, Richard Polenberg, Albert S. Roe, Joel H. Silbey, Walter J. Slatoff, James M. Smith, Fred Somkin, Gordon F. Streib, Robin M. Williams, Jr.

Although there is no formal program leading to a degree in American Studies, candidates for the doctorate in English and history will find ample opportunity to do interdisciplinary work in conjunction with a major in American Studies within their field. There are members of the staff in both fields who are professionally trained and currently active in the study of the interrelationships of American intellectual, literary, and social history, so that a student concentrating in American literature or American history may take advantage of the freedom permitted by Graduate School regulations and, in collaboration with his Special Committee, readily build an individual doctoral program that systematically embraces more than a single discipline. Inquiries concerning opportunities in this area should be addressed to: Professor S. Cushing Strout, Chairman, American Studies Committee, Goldwin Smith Hall.

Brookhaven National Laboratory

Cornell is one of nine eastern universities participating in Associated Universities, Inc. (AUI). Operating under contract with the Atomic Energy Commission, this corporation has the responsibility for the management of Brookhaven National Laboratory. The Laboratory provides unusual research facilities for studies in biology, chemistry, applied mathematics, medicine, physics, high energy particle physics, and reactor and nuclear engineering.

Graduate students may participate in research at Brookhaven by association with Cornell staff members who are engaged in research at the Laboratory. Members of a variety of science departments at Cornell are currently involved in programs at Brookhaven. The Laboratory also offers temporary summer appointments to a limited number of selected graduate and undergraduate students in science or engineering.

Center for Environmental Quality Management

The Center for Environmental Quality Management brings together the faculties of the Cornell Medical College in New York and the various colleges and schools in Ithaca to study the manifold questions of environmental health in both urban and rural settings.

Current approaches to the modification and control of the environment, in concentrating on limited objectives such as air quality control, disease control, water quality control, pest control, food sanitation, and occupational health have had limited success since they have been unable to take into account the interdependence of environmental health problems. The character and the urgency of the total environmental quality problem facing us appears insoluble short of an overall approach that will enable decision makers to consider simultaneously the significant variables and relationships relevant to the management of environmental quality.

Scientific management through systems analysis has begun to make it possible to consider these multiple relationships within the framework of common objectives and subject to predetermined constraints. It provides mechanisms by which various innovations can be examined in terms of their short- and long-term effects upon the environment. Such an approach provides rational bases for establishing environmental quality goals and for the allocation of scarce resources to achieve these goals.

The Center is frequently able to provide predoctoral and postdoctoral fellowships for students interested in pursuing research topics in environmental health. For information regarding specific programs, write to: Professor Walter R. Lynn, Director, Center for Environmental Quality Management, 302 Hollister Hall.

Center for Urban Development Research

The purpose of the Center for Urban Development Research is to enable the University to expand its research, training, and service in the field of urban problems. It is intended to provide a continuing forum for questions pertaining to urban development; encourage new combinations of interdisciplinary problem-centered research; encourage and cooperate with interdisciplinary educational developments; provide for participation by faculty, staff, and students on an interdisciplinary basis in urban studies; assure integration and dissemination of the results of research.

The Center supersedes the Center for Housing and Environmental Studies. The acting director of the Center is Professor Barclay G. Jones, 109 West Sibley Hall.

Center for Radiophysics and Space Research

The Center for Radiophysics and Space Research unites research and graduate education carried on by several academic departments in the space sciences. It furnishes administrative support and provides facilities for faculty members and graduate assistants who are engaged in space research activities, and it offers opportunity for graduate students to undertake thesis work leading to the degrees of Master of Science and Doctor of Philosophy. A student's major professor can be chosen from the following Fields in the Graduate School: Aerospace Engineering, Applied Physics, Astronomy and Space Sciences, Chemistry, Electrical Engineering, Physics.

Thesis research in the following areas is now possible:

(a) *Astronomy and astrophysics.* Astronomical aspects of cosmic rays, gamma-radiation, x rays, neutrinos; cosmology; experimental studies and theory relating to the surface of the moon and the planets; processes in the interstellar gas; solar-system magnetohydrodynamics; stellar statistics; theory of stellar structure, stellar evolution, nuclear processes in stars.

(b) *Atmospheric and ionospheric radio investigations.* Dynamics of the atmosphere; incoherent electron scattering; study of refraction, scattering, attenuation due to the inhomogeneous nature of the troposphere and ionosphere; theory and observation of propagation of radio waves in ionized media such as the ionosphere.

(c) *Radar and radio astronomy.* Distribution and classification of radio sources; radar investigations of the moon and planets; solar radio observations; studies of gaseous nebulae.

(d) *Space vehicle instrumentation.* Instrumentation relating to lunar exploration; magnetic field measurements; tenuous gas and particle flux measurements; infrared observations from rockets.

The facilities of the Center include the lunar surface and electronics laboratory on the Cornell campus, the radio astronomy and ionospheric laboratories close to Ithaca, and the Arecibo Observatory in Puerto Rico. At Arecibo an extremely sensitive radio telescope and an unusually powerful space radar are available for use by qualified graduate students. In addition, certain facilities of Sydney University, Australia, are available through the Cornell-Sydney University Astronomy Center (see p. 43).

Center for Research in Education

The Center for Research in Education provides an instructional focus within the University for the interests of faculty members from different disciplines in educational research and development. In addition, the Center attempts to stimulate investigation of socially significant educational problems and to train students in educational research. At present, research projects in adult-child interaction and cognitive socialization, in language development and literacy, in science education, and in early school learning are under way. Research programs in mathematics education and in undergraduate education are being planned.

The Center provides predoctoral and postdoctoral training through research assistantships, training grants, and postdoctoral fellowships. For information write to Professor Alfred L. Baldwin, Director, Center for Research in Education, Rand Hall.

Cornell-Sydney University Astronomy Center

The Center is an interuniversity organization designed to create a larger pool of facilities and skills for research in astronomy and related fields than would be separately available to either university. Graduate students can be interchanged between the two institutions whenever appropriate for the research work in which they are engaged. Both universities recognize research supervision extended by the sister university, and the time spent by a student on thesis work in the sister university can be accepted toward residence requirements with the proviso that the approval of the home research supervisor is given and also that the home university bylaws are not contravened.

The facilities available through the Center, in addition to those of Cornell's Center for Radiophysics and Space Research, are the one-mile by one-mile Mills Cross situated at Hoskintown, New South Wales; the stellar intensity interferometer situated at Narrabri, New South Wales; the Criss-Cross, the Shain Cross, and Mills Cross situated at Fleurs, New South Wales; the Wills Plasma Physics Department, the Basser Computing Department, the Falkner Nuclear Department, and the facilities of the cosmic ray group at the University of Sydney. The Center includes H. Messel, R. Hanbury Brown, W. N. Christiansen, C. B. A. McCusker, and B. Y. Mills from the University of Sydney faculty.

Further information can be obtained from Professor T. Gold, Joint Director, Cornell-Sydney University Astronomy Center, Space Sciences Building, Cornell University.

Developmental Studies

Specializations in this area normally involves participation in a program jointly sponsored by the Fields of Human Development and Family Studies, and Psychology. The program presently emphasizes cognitive development. Students interested in the program should apply to either the Field of Human Development and Family Studies or the Field of Psychology. Training in research skills in both Fields is recommended. Students admitted to the program fulfill the requirements of whichever Field they enter. Current research interests of the faculty include development of language, perception, thinking, intellectual development in natural settings, conceptual and affective behavior in infancy, cognitive socialization, and biological maturation. For further information see the description of the Field of Psychology and the Field of Human Development and Family Studies, or write to either Field Representative.

Division of Biological Sciences

The Division of Biological Sciences was established in 1964 to bring together into a single administrative unit a number of investigators and teachers representing a broad spectrum of interests in basic biology. Its members hold appointments in one or more of four schools and colleges but serve the University as a whole through the Division. The Division is responsible for all the undergraduate teaching of biology, including the establishment of requirements for the major in its various branches. It also has the primary responsibility for the promotion of research in basic biology, and its members, as part of the Graduate School Faculty, teach in appropriate Fields. At present the following subject areas are represented by separate sections of the Division: biochemistry and molecular biology; ecology and systematics; genetics, development, and physiology; microbiology; and neurobiology and behavior. A number of graduate fellowships, teaching fellowships, research assistantships, and traineeships are available through the Division. For further information, write to Professor Richard O'Brien, 201 Roberts Hall.

Materials Science Center

The Materials Science Center (MSC) at Cornell is an interdisciplinary laboratory created to promote research and graduate student training in all phases of the science of materials. The subjects of study represented in the MSC program are applied physics, chemistry, electrical engineering, materials engineering, materials science, mechanics, metallurgy, and physics.

The extent of the benefits a graduate student may derive from the MSC program depends on the actual research he pursues. If the student chooses to follow the more conventional course of becoming a specialist in one specific area, the MSC program could help him by providing new equipment, financial assistance through research assistantships, or, in some cases, the help of a technician to carry out routine measurements.

If the student wishes to follow a program of considerably more breadth than usual in his research training, the MSC program provides an additional advantage. Several central facilities have been set up where more specialized apparatus such as crystal-growing furnaces, high-pressure equipment, x-ray and metallography equipment, electron microscopes, etc., are available to all MSC members and their students. In addition to the equipment, expert advice on its use and the interpretation of the results will be available. In these central facilities, it is expected that the student will come in contact with students from other disciplines, resulting in a mutually profitable interaction.

The office of the Director of the Materials Science Center, Professor R. E. Hughes, is in Room 627, Clark Hall.

Plasma Physics

Established in 1966, the Laboratory for Plasma Studies at Cornell enables students and faculty members to deal with plasma, electron, and laser physics on a unique, interdisciplinary basis. In the future, plasmas will provide power for cities, will power spacecraft, will help to explain the composition of the universe, and may unlock the energy resources of the sea. Nothing less than an integrated scientific and technological approach to these and other vital areas of plasma research is feasible.

The unified, interdisciplinary approach to plasma studies has added a new dimension to education at Cornell, enabling the University to give the best counsel to graduate students who want to combine their knowledge of some field of science or engineering with work in plasma studies. A program now exists whereby graduate study in plasma physics is offered to students in aerospace engineering, applied physics, chemistry, electrical engineering, mechanical engineering, and physics.

Graduate research assistantships are available through the Cornell Laboratory for Plasma Studies as well as from several departments within the University. It is also possible to obtain positions as postdoctoral research associates with the Laboratory. Prospective graduate students should also consider applying for fellowships awarded on a national basis by the Atomic Energy Commission and the National Science Foundation. The deadlines for these programs are usually in the fall for the following academic year. For further information, write to Professor Peter L. Auer, Director, Laboratory for Plasma Studies, Upson Hall.

Program on Science, Technology, and Society

F. A. Long, director; R. Bowers, deputy director; R. A. Rettig, executive secretary. Steering Committee: P. Bereano, U. Bronfenbrenner, M. Drosdoff, G. Gordon, E. Heitowit, G. Likens, W. Lynn, R. Morison, M. Nelkin, C. Stern, G. Winter

The purpose of the interdisciplinary Program on Science, Technology, and Society is to stimulate teaching and research on the interaction of science and technology with contemporary society. The Program is initiating a number of new research and teaching efforts and also plays a role in providing coherence and support to activities in this area which are already proceeding at the University.

The topics of concern to the Program are illustrated by the following examples: science, technology, and national defense; world population and food resources; legal and moral implications of modern biology and medicine; national policy for the development of science; sociology of science; the ecological impact of developing technology.

The mechanisms for studying these problems will vary and will probably include courses, seminars, short workshops, and summer studies as well as individual research programs. The Program welcomes the participation of students and faculty from all colleges and schools. A list of relevant courses in all parts of the University may be obtained from the Program office, Clark Hall.

Society for the Humanities

Henry Guerlac, director. Fellows (1970–71): Darrell Jackson (Queens College), Philosophy; Paul Schwaber (Wesleyan University), Literature; Hayden White (University of California, Los Angeles), History; Joseph Kerman (University of California, Berkeley), Music; Bojan Bujic (University of Reading, England), Music; Edward Morris and Thomas Hill (Cornell University), Romance Literature and English Literature.

The Society awards three categories of fellowships for research in the humanities: Senior Visiting Fellowships, Faculty Fellowships, and Junior Postdoctoral Fellowships. The Fellows offer, in line with their research, informal seminars intended to be off the beaten track. Details about these seminars are circulated to interested departments.

Membership in the Society's seminars is open, upon written application, to graduate students and suitably qualified undergraduates. All seminars are held in the Society's house at 308 Wait Avenue. Only those officially enrolled, or specifically invited to attend, are admitted as visitors.

A student wishing to attend any of these seminars should write to the Secretary of the Society, 308 Wait Avenue, Ithaca, New York 14850, giving his name, address, telephone number, and a brief summary of his qualifications.

Statistics Center

The methods of statistics find important applications in many diverse fields of research. It is therefore necessary that (1) subject matter specialists be able to obtain assistance in using or developing statistical theory, (2) students who intend to do research work in a particular field which makes extensive use of statistical methods receive adequate training in statistics, and (3) individuals be trained as statisticians.

The staff members of the various schools and colleges of Cornell University who are interested in the development and application of statistical methods are associated with the Cornell Statistics Center. A major responsibility of the Center is to provide a focal point to which individuals, projects, and departments may come to receive assistance and guidance with respect to the statistical aspects of research and training programs.

The acting director of the Center is Professor Philip J. McCarthy, Ives Hall.

Center for Water Resources and Marine Sciences

The Center is an interdisciplinary organization serving the entire University at the graduate study and research level. Its purpose is to promote and coordinate a comprehensive program in water resources planning, development, and management that includes the sciences, engineering, agriculture, law, economics, government, regional planning, and public health.

Its responsibilities are to undertake and support water resources research in engineering, in the physical, biological, and social sciences, and in the humanities; to encourage and contribute to graduate studies in water resources; to coordinate research and training activities in water resources; to encourage new combinations of disciplines in research and training which can be brought to bear on water resource problems; to disseminate the results of research; and to develop and operate central facilities which may be needed to serve participants in research and training.

Correspondence concerning the Center should be directed to Professor L. B. Dworsky, Director, Center for Water Resources and Marine Sciences, Hollister Hall.

Correspondence related to graduate study in the Field of Water Resources should be directed to the Field Representative, Professor C. D. Gates, Hollister Hall.

Special Facilities and Service Organizations

Military Science, Naval Science, and Aerospace Studies (ROTC, NROTC, and AFROTC)

The advanced course in military science (Army ROTC), naval science (Naval ROTC), and aerospace studies (Air Force ROTC) is open to graduate students who have satisfactorily completed a basic course in ROTC or who enroll in a two-year ROTC program. Successful completion of a two-year advanced ROTC course will qualify a graduate student for appointment as a second lieutenant in the United States Army, Air Force, or Marine Corps Reserve; or ensign in the United States Naval Reserve; or as second lieutenant in the Regular Army or Air Force. Interested graduate students should consult the *Announcement of Officer Education* and apply to Professor of Military Science, Professor of Naval Science, or Professor of Aerospace Studies (ROTC), Barton Hall.

New York State Agricultural Experiment Station at Geneva

The New York State Agricultural Experiment Station was established in 1880 to promote agriculture through scientific investigations and experimentation. It is located at Geneva, fifty miles from Ithaca, and has been under the administration of Cornell University since 1923.

Professors on the Geneva staff are eligible to serve as members of the Special Committees of graduate students along with professors on the Ithaca campus of the University. Normally the graduate training provided at Geneva consists of research experience and supervision of the student's work on a thesis problem. The formal course work of the student's training program is given on the Ithaca campus. Student who plan to do part of their graduate work at Geneva should correspond with their major advisers or with the dean of the Graduate School concerning regulations as to residence, Special Committees, etc.

The Station is equipped to care for graduate students in certain specific lines of research, viz., chemistry, economic entomology, food technology, microbiology, plant pathology, pomology, seed investigations, and vegetable crops. Ample facilities are available for graduate research under laboratory, greenhouse, pilot plant, insectary, orchard, and other field conditions.

Certain phases of the investigations now being conducted at the Station and other problems for which the facilities of the Station are suitable may be used as thesis problems by graduate students.

The director is Professor D. W. Barton, who may be addressed at the New York State Agricultural Experiment Station, Geneva, New York 14456.

Office of Computer Services

The principal computing facility at Cornell is an IBM 360 Model 65 located at Langmuir Laboratory at the Cornell Research Park. The system is equipped for remote access of several kinds, and the operating system is designed so that very few users find it necessary to visit Langmuir. The primary terminals are high-speed reader-printers located in Upson, Clark, and Warren Halls. While these are remote job-entry and delivery devices rather than conversational terminals, they permit convenient access, job turnaround-time in terms of minutes, and the use of on-line files. Each of these terminals is the core of a small computing center, with auxiliary equipment, consulting assistance, reference material, and work space. In addition to these high-speed terminals, teletypewriter terminals are available to individual projects that require interactive capability. This computing system is busy but not saturated, and use by graduate students is encouraged.

The University has one IBM 1800 computer, which is located in the Wilson Synchrotron Laboratory.

The Office of Computer Services is responsible for the operation of this system and for the provision of consulting and programming assistance. The Office cooperates with the Department of Computer Science in providing courses in programming and computing techniques. The Department of Computer Science employs a limited number of graduate students on assistantships for this work.

For further information write to the Office of Computer Services, Langmuir Laboratory.

University Press

Cornell University Press, founded by Andrew D. White in 1869, was the first university press in America and is among the leaders in number of volumes published annually. The Press publishes scholarly books on nearly every academic subject, serious nonfiction of general interest, and advanced or experimental textbooks for universities. The imprint of Comstock Publishing Associates, a division of the Press, is placed on certain books in the biological sciences. The Press also publishes a paperbound series, Cornell Paperbacks. More than twenty percent of the books published by the Press in recent years were written by members of the Cornell University faculty. All printing for the Press is done under contract by various book manufacturing firms; the Press has no production facilities of its own.

Visual Aids

The University owns and operates the Photo Science Studios, which create, or cooperate in the creation of, photographic studies and visual aids of all kinds.

The extension services of the New York State Colleges, which form integral parts of the University, disseminate knowledge through an intensive program of publication, photography, and recording supervised by professional staffs. Materials produced by graduate students may find outlets through these channels.

Other Research Units

Some other research units allied with the University, either as wholly owned and operated divisions or as wholly or partially autonomous organizations with which the University has a working agreement, are the Sloan-Kettering Cancer Research Institute in New York City, through the Graduate School of Medical Sciences, and the Veterinary Virus Research Institute in Ithaca.

Cornell is also one of fourteen founding members of the University Corporation for Atmospheric Research which, under National Science Foundation support, operates the National Center for Atmospheric Research at Boulder, Colorado. In addition to Brookhaven National Laboratory, Cornell, as a member of Associated Universities, Inc., has access to the facilities of the National Radio Astronomy Observatory in Greenbank, West Virginia.

Further opportunities for formal study, field work, and independent research by Cornell graduate students are available in many institutions, laboratories, and libraries both in the United States and in other countries. For example, the Cornell-Harvard Archaeological Exploration at Sardis, Turkey, and the Museum of Northern Arizona at Flagstaff, Arizona, both provide opportunities for field research related to doctoral work of Cornell graduate students. Information on that kind of arrangement is available directly from the Field Representatives.

Fields of Instruction

Aerospace Engineering

Faculty
Peter L. Auer, P. C. Tobias de Boer, Richard H. Gallagher, Albert R. George, Geoffrey S. S. Ludford, Edwin L. Resler, Jr., William R. Sears, A. Richard Seebass, Shan-fu Shen, Donald L. Turcotte

Field Representative
Donald L. Turcotte, 289 Grumman Hall

MAJOR SUBJECT
Aerospace Engineering

MINOR SUBJECTS
Aerospace Engineering
Aerodynamics

The requirement for admission in this Field is a Bachelor's degree in engineering or the physical sciences. It is not recommended that candidates apply for admission at midyear, except in unusual cases.

The language requirement for the Ph.D. is one language in addition to the candidate's native language: either French, German, or Russian at the level of the ETS Language Examination, or English.

Candidates for an advanced degree with a major in this Field who do not already hold the Master's degree are encouraged to matriculate first as candidates for the professional degree, Master of Engineering (Aerospace), under the jurisdiction of the Graduate School of Aerospace Engineering. Information concerning this School and the degree of M.Eng. (Aerospace) will be found in the *Announcement of the College of Engineering*.

There is no final comprehensive examination required for this Master's degree. Ph.D. candidates must take the admission to candidacy and final thesis examinations required by the Graduate School and described on p. 11 of this *Announcement*.

In this Field, emphasis is placed on the aerospace sciences rather than proficiency in present-day techniques. Consequently, students who major in aerospace engineering are urged to minor in the basic sciences, such as chemistry, mathematics, mechanics, and physics.

Much of the research in this Field is concerned with fundamental problems in the dynamics of fluids, including plasmas, and chemical reactions at high temperature. Whenever possible, these investigations combine the techniques of theory and laboratory experiment, making use of the experimental facilities of the Graduate School of Aerospace Engineering on the campus.

A group, working under the direction of Professors de Boer and Resler, is investigating the dynamics of gases at high temperatures, including applications to gas lasers. Much of this work is carried out in shock tubes. Problems on the interaction between radiation and flow fields are included, e.g., laser-induced blast waves.

Research in magnetohydrodynamics and continuum plasma physics, both in theory and in the laboratory, is carried out by Professors Auer, Sears, and Turcotte. Professor Ludford of the Department of Theoretical and Applied Mechanics is exploring the mathematical theory of this phase of fluid mechanics. Professor Auer, Director of the Laboratory of Plasma Studies, is also concerned with those aspects of plasma physics concerned with the higher temperature collisionless regime appropriate to possible fusion applications. These interests bring the School into close contact with other departments of the University (including the Center for Applied Mathematics, the Laboratory of Plasma Studies, and the Center for Radiophysics and Space Research). Professors George, Seebass, and Shen and their students are pursuing investigations in the area of rarefied-gas dynamics, hypersonics, basic fluid mechanics, and advanced aerodynamics, which are related to the other aspects of real-gas dynamics and air chemistry mentioned above. The staff is also actively engaged in studies of the sonic boom and associated problems concerned with high-performance aircraft. Professors Sears and George and their students are also carrying out research on noise generation by engines, helicopters, and other aerodynamic sources. Close contact is maintained with the work in Thermal Engineering, which is housed in Upson Hall adjacent to this School. The School also maintains active interest and research in subjects basic to modern space vehicle and propulsion-system design, including problems of missile dynamics, trajectories, and orbits. This work is conducted in collaboration with the members of the Department of Theoretical and Applied Mechanics. Research in chemical kinetics is conducted with the cooperation of Professor S. H. Bauer of the Department of Chemistry, and research in structures and materials is carried out in cooperation with the Fields of Theoretical and Applied Mechanics and Civil Engineering, and the Materials Science Center. Other projects concern geological fluid flows (Professor Turcotte) and ferrohydrodynamics (Professor Resler). This brief description is, of course, not all-inclusive and other topics of research are under study. Further details may be obtained by writing to: Director of the Graduate School of Aerospace Engineering, Grumman Hall.

Courses

7101 Advanced Kinetic Theory. Fall term. Credit three hours.

The Boltzmann equation. Conservation equations. Hilbert-Enskog-Chapman theory of transport coefficients. Grad's thirteen moment equations. The BGK equation. The BBGKY hierarchy of equations. Fluctuations.

7102 Gasdynamics. Spring term. Credit three hours.

Strong shock waves and their use in the production and study of high temperature gases. High temperature chemical kinetics and applications. Theory of characteristics including chemical reactions. Experimental techniques.

7103 Dynamics of Rarefied Gases. Spring term. Credit three hours. Prerequisite: 7101.

Flow regimes according to the Knudsen number. Free-molecule flows. Eigen function expansion of the linearized Boltzmann equation. Full-range and half-range moment methods.

7104 Advanced Topics in High Temperature Gasdynamics. Either term. Credit three hours. Prerequisite: 7101 and 7102.

Current topics relating to present engineering practice and/or research interests of the faculty and staff. One or more of the following topics may be included: the physics of lasers; electro-fluid-dynamics; molecular relaxation phenomena; collision cross sections.

7201 Introductory Plasma Physics. Fall term. Credit three hours.

Particle orbits in electric and magnetic fields, adiabatic invariants, Coulomb scattering, transport phenomena, plasma oscillations and waves, hydromagnetic equations, energy principle and instabilities, controlled thermonuclear research. At the level of Longmire, *Elementary Plasma Physics.*

7202 Introductory Magnetohydrodynamics. Spring term. Credit three hours.

Basic equations of magnetohydrodynamics. Flow problems. Hydromagnetic shock waves. The pinch effect and instabilities. Tensor conductivity and excess electron temperature.

7203 Intermediate Plasma Physics. Spring term. Credit three hours. Prerequisite: Electrical Engineering 4561 or 7201 or equivalent.

Collective oscillations in a plasma. Nonlinear theory of collision-free shocks. Introduction to radiation and scattering in plasmas. At the level of Stix, *Theory of Plasma Waves,* and Bekefi, *Radiation Processes in Plasmas.*

7301 Fluid Mechanics. Fall term. Credit three hours.

Cartesian tensors, stress, strain, constitutive equations and the fundamental equations of continua. Boundary conditions. Fluid mechanics, including the effects of viscosity, boundary layer concepts, ideal fluid flow and vorticity.

7302 Aerodynamics. Spring term. Credit three hours.

Methods of ideal incompressible fluid flow for plane and axisymmetric flows and wings. Acoustics, compressible subsonic and supersonic flow, shock waves, boundary layer, heat transfer, separation.

7303 Compressible Fluid Flow. Spring term. Credit three hours.

Aerodynamics of compressible fluids. Characteristics for three-dimensional rotational, reacting flows. Supersonic linearized flow theory. Higher order theories and sonic boom. Shock waves and related phenomena.

7304 Theories of Viscous Flows. Either term. Credit three hours. Prerequisite: 7301 and 7302.

Exact solutions of the Navier-Stokes equations. Small Reynolds number approximation. Boundary layer theory. Stability of laminar flows. Turbulence.

7305 Hypersonic Flow Theory. On demand. Credit three hours. Prerequisite: 7301 and 7302.

Hypersonic small disturbance theory; blast waves; entropy layers. Newtonian theory and shock layers. The blunt body problem. Viscous and real gas effects.

7306 Current Topics in Fluid Mechanics. Either term. Credit three hours.

Current topics relating to present engineering practice and/or research interests of the faculty and staff.

7307 Acoustics and Aerodynamic Noise. Either term. Credit three hours.

Basic acoustics and sound propagation. Generation of noise by surfaces, turbulence and unsteady flows and application to aircraft noise.

7801 Research in Aerospace Engineering. Throughout the year. Credit to be arranged. Prerequisite: admission to the Graduate School of Aerospace Engineering and approval of the director.

7901 Aerospace Engineering Colloquium. Throughout the year. Credit one hour.

Lectures by Cornell staff members, graduate students, and visiting scientists.

7902 Seminar in Aerospace Engineering. Throughout the year. Credit two hours. Prerequisite: approval of the director.

Study and discussion of topics of current interest in aerospace engineering. Participants prepare and deliver reports based on published literature.

7903 Plasma Physics Colloquium. Fall and spring terms. Credit one hour.

Lectures by staff members, graduate students, and outside scientists on topics of current interest in plasma research.

Agricultural Engineering

Faculty
Richard D. Black, J. Robert Cooke, Edward W. Foss, Orval C. French, Ronald B. Furry, Richard W. Guest, Wesley W. Gunkel, Fred G. Lechner, Gilbert Levine, Raymond C. Loehr, Robert T. Lorenzen, David C. Ludington, Everett D. Markwardt, William F. Millier, Gerald E. Rehkugler, Norman R. Scott, E. Stanley Shepardson, James W. Spencer

Field Representative
Ronald B. Furry, 218 Riley-Robb Hall

MAJOR AND MINOR SUBJECTS
Agricultural Engineering
Agricultural Structures
Agricultural Waste Management
Electric Power and Processing
Power and Machinery
Soil and Water Engineering

Ph.D. candidates are required to select one major subject from the above list, and two minor subjects, at least one of which must be selected outside the Field. M.S. candidates are required to take agricultural engineering as their major subject and to select one minor outside the Field. Candidates for either the doctorate or the Master's degree with the major outside the Field may select any subject as a minor.

ADMISSION REQUIREMENTS. An applicant must have a baccalaureate degree in an area of engineering, physical science, or biological science from a faculty or university of recognized standing. Training in the engineering and biological sciences is necessary. Any deficiencies in these areas in the undergraduate training will need to be satisfied early in the advanced degree program. The applicant must present evidence of promise in advanced study and research as indicated by past scholastic achievement and recommendations from his undergraduate or graduate institution.

Applicants requesting fellowships are strongly urged to submit scores of the Graduate Record Examination Aptitude and Advanced Engineering Tests as part of the application.

LANGUAGE REQUIREMENT. There is no general language requirement for either the M.S. or the Ph.D. degree in the Field. However, a candidate's Special Committee may require a language to be included in his program.

EXAMINATIONS. The final examination for the M.S. degree may be oral, or oral and written. An admission to candidacy examination and a final examination on the thesis are required of all Ph.D. candidates.

RESEARCH AND STUDY OPPORTUNITIES. A broad spectrum of research and study activity is available in Agricultural Engineering. A thesis based on research effort is required for both the M.S. and Ph.D. degrees. A partial list of the general areas of research interest and the faculty members associated with these interests appears below. Specific topics of mutual interest may also be selected. For information about current research projects, write to the Field Representative, who will direct inquiries to the faculty member best able to answer specific requests.

Agricultural Engineering: All faculty members. Agricultural mechanization, agricultural waste management, bioengineering, engineering properties of biological materials, secondary road systems, materials handling, safety engineering.

Agricultural Structures: Ronald B. Furry, Robert T. Lorenzen, Norman R. Scott. Structural analysis and design, production systems synthesis, structural-biological relationships, environmental composition and control, biological response to environment, thermodynamic processes.

Agricultural Waste Management: Raymond C. Loehr and David C. Ludington. Biological, physical, and chemical waste treatment, incineration, odor control, waste handling, source control of wastes, waste management systems, waste characterization.

Electric Power and Processing: Ronald B. Furry, Richard W. Guest, E. Stanley Shepardson. Electrical control systems, processing of agricultural materials, application of electromagnetic radiation to agriculture.

Power and Machinery: J. Robert Cooke, Richard W. Guest, Wesley W. Gunkel, Everett D. Markwardt, William F. Millier, Gerald E. Rehkugler, E. Stanley Shepardson. Agricultural machinery design and development, terramechanics, crop harvesting, handling and processing systems, metering and distribution of agricultural chemicals, physical and biological factors pertaining to machine design such as soil mechanics in relation to seedling development.

Soil and Water Engineering: Richard D. Black and Gilbert Levine. Surface water hydrology, drainage, irrigation, soil-plant-water relationships, hydraulics, and erosion control.

Professional Degree

The Department of Agricultural Engineering also offers the professional degree of Master of Engineering (Agricultural) which is intended primarily for those students who plan to enter engineering practice and not for those who expect to study for the doctorate. This program consists of courses which are intended to develop the student's background in engineering design as well as strengthen his fundamental engineering base. Of the required thirty hours, six consist of engineering design experience involving individual effort and a formal report.

Admission to the program is open to persons who have been granted Bachelor's degrees or the equivalent and who have sufficient training to indicate that they can profitably study the advanced courses offered for these students in engineering. A student can choose to concentrate his studies in one of the subareas of Agricultural Engineering or to take a broad program without specialization.

Graduate Courses

501 Similitude Methodology. Spring term. Credit three hours. Two lectures, one laboratory. Mr. Furry.

Similitude methodology, including the use of dimensional analysis to develop general equations to define physical phenomena; model theory; distorted models; and analogies; with an introduction to a variety of applications in engineering. Problem solutions will employ both analog and digital computers. It is preferred that the student know how to program in FORTRAN, although knowledge of CUPL is acceptable.

502 Instrumentation. Spring term. Credit three hours. Prerequisite: consent of the instructor. Two lectures, one laboratory. Mr. Scott.

Emphasis on the application of instrumentation concepts and systems to physical and biological measurements. Characteristics of instruments, signal conditioning, shielding and grounding; transducers for measurement of force, pressure, displacement, velocity, acceleration, temperature, humidity, flow; and data acquisition systems, including telemetry, are covered.

504 Biological Engineering Analysis. Fall term. Credit four hours. Three lectures. Prerequisite: consent of the instructor or Engineering 1151. Mr. Cooke.

Engineering problem-solving techniques will be examined. Particular attention will be given to the formulation of biological problems in an engineering context. Problem definition, mathematical formulation, and interpretation of results will be emphasized. Principles of feedback control theory will be studied and applied to biological and technological systems.

[**505 Solid Waste Management (Civil Engineering 2530).** Spring term. Credit three hours. Three lectures. Prerequisite: consent of the instructor. Mr. Loehr. Offered in alternate years; not offered in 1971–72.

Study of municipal, industrial, and agricultural solid wastes. Emphasis on waste characteristics, methods of treatment and disposal, and interrelationships with the air, water, and land environment. Discussion of economic and political aspects. Enrollment also open to nonengineering students.]

506 Industrial Waste Management (Civil Engineering 2531). Spring term. Credit three hours. Three lectures. Prerequisite: consent of the instructor. Mr. Loehr. Offered in alternate years.

Legal aspects, assimilatory capacity of receiving waters, waste sampling and analysis, treatment processes, waste reduction possibilities, waste quantity and quality, reuse and recovery, joint industry-municipal treatment of wastes, sewerage service charges, case studies. Emphasis on liquid industrial wastes.

551–552 Agricultural Engineering Project. Fall and spring terms (both terms required for M.Eng. (Agr.) degree). Credit three hours per term. Staff.

Comprehensive design projects utilizing real engineering problems to present fundamentals of agricultural engineering design. Emphasis on formulation of alternate design proposals, including economics and nontechnical factors, and complete design of the best alternative.

601 Agricultural Engineering Seminar. Fall and spring terms. Fall term required of all graduate students majoring in the Field. Spring term optional. Riley-Robb 400. Staff.

Presentation and discussion of research and special developments in agricultural engineering and other fields.

602 Power and Machinery Seminar. Spring term. Credit one hour. Prerequisite: consent of the instructor. Staff.

Study and discussions of research and new developments in agricultural power and machinery.

603 Soils and Water Engineering Seminar. Spring term. Credit one or two hours. Prerequisite: consent of the instructor. Staff.

Study and discussion of research on selected topics in irrigation, drainage, erosion control, and agricultural hydrology.

604 Agricultural Structures Seminar. Spring term. Credit one hour. Prerequisite: consent of the instructor. Staff.

Study and discussion of farmstead production problems, with emphasis on biological, economic, environmental, and structural requirements.

605 Agricultural Waste Management Seminar. Fall and spring terms. Credit one hour. Prerequisite: consent of the instructor. Messrs. Loehr and Ludington.

Study and discussion of the management of agricultural wastes, with emphasis on the physical, chemical, biological, economic and aesthetic considerations.

606 Biological Engineering Seminar. Spring term. Credit one hour. Prerequisite: consent of the instructor. Messrs. Cooke and Scott.

The interaction between engineering and biology will be examined, especially the environmental aspects of plant, animal, and human physiology, in order to improve communications between engineers and biologists.

Undergraduate Courses Open to Graduate Students

421 Introduction to Environmental Pollution. Fall term. Credit three hours. Three lectures. Mr. Ludington.

A general course dealing with the impairment of the environment by the wastes of man. The causes and effects of air, water, and soil pollution will be discussed. Fundamental factors underlying waste production, abatement, treatment, and control. A selected number of wastes from urban, rural, and industrial areas will be used to illustrate the factors.

[**461 Agricultural Machinery Design.** Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: Engineering 3331 or equivalent. Mr. Gunkel. Offered in alternate years; not offered in 1971–72.

The principles of design and development of agricultural machines to meet functional requirements. Emphasis is given to computer-aided analysis and design, stress analysis, selection of construction materials, and testing procedures.]

462 Agricultural Power. Fall term. Credit three hours. Two lectures, one laboratory. Mr. Rehkugler. Offered in alternate years.

Basic theory, analysis, and testing of internal combustion engines specifically for use in farm tractors and other agricultural power applications. Tractor design for utilization of internal combustion engine power is studied with respect to tractor transmissions, Nebraska Tractor Tests, soil mechanics, vehicle stability and dynamics, hydraulically powered equipment, and human factors in operator comfort and safety.

[**463 Processing and Handling Systems for Agricultural Materials.** Spring term. Credit four hours. Three lectures, one laboratory. Mr. Furry. Offered in alternate years; not offered in 1971–72.

Processes such as size reduction, separation, metering, and drying will be studied. Psychrometrics, fluid flow measurement, and an introduction to dimensional analysis and controls for agricultural applications are included. Problem solutions will employ both the analog and digital computers. It is preferred that the student know how to program in CUPL.]

471 Soil and Water Engineering. Spring term. Credit three hours. Three lectures, one laboratory every other week. Prerequisite: fluid mechanics and soils, or concurrent registration. Mr. Black. Offered in alternate years.

The application of engineering principles to soil and water control in agriculture. Includes design and construction of drainage systems and farm ponds, design and operation of sprinkler systems for irrigation.

481 Agricultural Structures. Spring term. Credit three hours. Prerequisite: structural engineering and thermodynamics. Mr. Scott. Offered in alternate years.

Synthesis of complete farmstead production units including structures, equipment, and management techniques. Integrated application of structural theory, thermodynamics, machine design, and methods engineering to satisfy biological and economic requirements.

491 Highway Engineering. Credit three hours. Offered upon sufficient demand, usually in fall term. Prerequisite: consent of the instructor. Principally directed study and individual or team investigations with one class session of two and a half hours per week. Mr. Spencer.

Emphasis is on secondary roads in study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

NOTE: For courses primarily designed to satisfy the needs of teachers of Vocational Agriculture relative to the subject matter areas of farm electrification, farm welding, small gasoline engines, and farm tractors, consult the *Summer Session Announcement* for the current topic to be offered. Credit two hours. Mr. Lechner.

Applied Mathematics

Faculty
Louis J. Billera, Henry David Block, James H. Bramble, Kenneth M. Brown, Herbert J. Carlin, Constantine Dafermos, Joseph C. Dunn, Roger Farrell, Michael E. Fisher, Wolfgang H. J. Fuchs, Leonard Gross, Frederick Jelinek, Harry Kesten, Jack Kiefer, James A. Krumhansl, Sidney Leibovich, Simon A. Levin, William F. Lucas, G. S. S. Ludford, Anil Nerode, Lawrence E. Payne, Narahari U. Prabhu, Sol Rubinow, Edwin E. Salpeter, Alfred H. Schatz, William R. Sears, A. Richard Seebass, Shan-fu Shen, Frank L. Spitzer, Benjamin Widom

Field Representative
Lawrence E. Payne, 275 Olin Hall

MAJOR SUBJECT

Applied Mathematics*

The graduate program in Applied Mathematics is based on a solid foundation in pure mathematics; it includes a thorough grounding in mathematical methods and studies of subject areas in which significant applications of mathematics are made. A new program of study in the area of mathematical biology has recently been initiated through the help and cooperation of the Biomathematics Group at the Cornell Medical School.

ADMISSION REQUIREMENTS. Students from a variety of educational backgrounds, including the several branches of engineering and the physical and biological sciences as well as mathematics, may be admitted.

LANGUAGE REQUIREMENT. A candidate for the degree of Ph.D. must demonstrate a reading knowledge in either French, German, or Russian. Testing will be done by a Field-appointed examiner, but can be waived if the student passes an appropriate language course or examination (such as ETS).

OTHER FIELD REQUIREMENTS. To be admitted to candidacy for the Ph.D. degree or to obtain a Master's degree a student must:

A. be familiar with advanced calculus (Math 411–412) and elementary abstract algebra (Math 431–432);

B. satisfactorily complete Math 415–416 or Mechanics 1182–1183;

C. pass one of the following combinations of subjects in mathematics: (1) 511–512, (2) 521–522, (3) 521–531, (4) 511–531.

Requirement A may be met either by a satisfactory grade on the written examination administered by the Department of Mathematics in September or by taking and mastering these courses with a high degree of competence. The admission to candidacy examination will consist of the final examinations in the required courses followed by an oral examination given by the candidate's Committee. Normally a student will be able to satisfy these candidacy requirements at the end of his second year, but in each individual case the student's Committee will decide the appropriate timing.

Each candidate for the degree must acquire familiarity with significant applications of advanced mathematics. Such applications may be studied at Cornell in several areas such as the various fields of engineering, biology, physics, chemistry, mathematics, and computer science. The specific courses may be chosen by the student with the consent of his Special Committee.

In consultation with the major adviser, minor subjects may be chosen from the biological, engineering, physical, and social sciences. One minor subject must be chosen in some area outside of mathematics and applied mathematics. Only one minor subject is required.

The thesis in Applied Mathematics must be a mathematical contribution toward the solution of a problem arising outside mathematics.

AREAS OF INTEREST

L. J. Billera, Assistant Professor of Operations Research: game theory, combinational mathematics.

H. D. Block, Professor of Theoretical and Applied Mechanics: nonlinear mechanics, automata, functional analysis.

J. H. Bramble, Professor of Mathematics: numerical analysis and partial differential equations.

* Applied Mathematics will be available as a minor subject in unusual cases when a minor in mathematics or in another related field does not meet the educational objectives.

K. M. Brown, Assistant Professor of Computer Science: numerical analysis.
H. J. Carlin, J. Preston Levis Professor of Engineering: microwave and network techniques.
C. M. Dafermos, Assistant Professor of Theoretical and Applied Mechanics: continuum mechanics, analysis.
J. C. Dunn, Professor of Theoretical and Applied Mechanics: optimal control theory.
R. Farrell, Professor of Mathematics: probability and statistics.
M. E. Fisher, Professor of Mathematics and Chemistry: foundation and applications of statistical mechanics.
W. H. J. Fuchs, Professor of Mathematics: mathematical methods of physics.
L. Gross, Professor of Mathematics: analysis, mathematics of quantum theory.
F. Jelinek, Associate Professor of Electrical Engineering: information theory, coding, communication networks, automata.
H. Kesten, Professor of Mathematics: probability theory.
J. C. Kiefer, Professor of Mathematics: probability and statistics.
J. A. Krumhansl, Professor of Physics: mathematical physics, microscopic processes, macroscopic descriptions.
S. Leibovich, Assistant Professor of Thermal Engineering: fluid dynamics, magnetohydrodynamics.
S. Levin, Assistant Professor of Mathematics: mathematical analysis, partial differential equations, biomathematics.
W. F. Lucas, Associate Professor of Operations Research: game theory, combinatorial mathematics, graph theory.
G. S. S. Ludford, Professor of Applied Mathematics: fluid mechanics, magneto-fluid dynamics.
A. Nerode, Professor of Mathematics: mathematical logic, recursive functions and computability, algebra, automata.
L. E. Payne, Professor of Mathematics: partial differential equations.
N. U. Prabhu, Professor of Operations Research: stochastic processes, queues and inventories, reliability.
S. Rubinow, Professor of Biomathematics (Cornell Medical College): blood flow, cell proliferation.
E. E. Salpeter, Professor of Physics and Astronomy: theoretical astrophysics, nuclear theory, statistical mechanics.
A. H. Schatz, Assistant Professor of Mathematics: partial differential equations.
W. R. Sears, John L. Given Professor of Engineering: aerodynamics, magneto-fluid dynamics.
A. R. Seebass, Associate Professor of Aerospace Engineering: aerodynamics, fluid mechanics.
S. F. Shen, Professor of Aerospace Engineering: aerodynamics, rarefied gasdynamics.
F. L. Spitzer, Professor of Mathematics: probability theory and analysis.
B. Widom, Professor of Chemistry: physical chemistry, statistical mechanics.

Applied Physics

Faculty
Peter L. Auer, Joseph M. Ballantyne, Robert W. Balluffi, Boris W. Batterman, John M. Blakely, K. Bingham Cady, David D. Clark, Roderick K. Clayton, Terrill A. Cool, Edmund T. Cranch, Trevor R. Cuykendall, P. C. Tobias de Boer, Lester F. Eastman, Michael E. Fisher, Hans H. Fleischmann, Thomas Gold, Paul L. Hartman, Martin O. Harwit, Herbert H. Johnson, Edward J. Kramer, James A. Krumhansl, Arthur F. Kuckes, Charles A. Lee, Che-Yu Li, Richard L. Liboff, Ross McFarlane, Paul R. McIsaac, Ross McPherson, Mark S. Nelkin, Edwin L. Resler, Jr., Thor N. Rhodin, Norman Rostoker, Arthur L. Ruoff, Henri S. Sack, Miriam H. Salpeter, David N. Seidman, Benjamin M. Siegel, John Silcox, Ravindra N. Sudan, Chung-Liang Tang, Donald L. Turcotte, Watt W. Webb, Charles B. Wharton, George J. Wolga

Field Representative
John Silcox, Clark Hall

MAJOR AND MINOR SUBJECT
Applied Physics

OBJECTIVES. Graduate study in the Field offers the opportunity to achieve proficiency in physics, mathematics, and applied science. The course program resembles a major in physics, and applied physics is particularly suitable for students preparing for a scientific career in areas of applied science based on principles and techniques of physics and in associated areas of physics. It provides a means for students with undergraduate training in physics to branch out into applied science while continuing the study of physics, and for students with backgrounds in engineering or another science to extend their knowledge of physical science principles and techniques.

A student may choose for specialization and thesis research any subject that is compatible with an approach based on the application of principles of physics and mathematics. Individual programs of study are planned to meet the needs and interests of each student, and programs involving several academic disciplines and topics that are undergoing transition from fundamental physics to applied science are readily accommodated.

Current areas of advanced study and research include: applied theoretical physics, biophysics, chemical physics, physics of fluids, nuclear and reactor physics, optics, plasma physics, radiation and matter, solid state physics and materials science, space physics, and surface physics.

FINANCIAL AID. Students in Applied Physics usually receive financial aid through fellowships, research assistantships, teaching fellowships, and tuition and fees scholarships during their entire graduate study program if they are making satisfactory progress toward an advanced degree. However, financial aid for a foreign student is not usually available his first year.

For information about fellowships available through Cornell University, and about teaching and research assistantships, see pp. 13–15 in this *Announcement*. In addition, there are several fellowships restricted to graduate students in Applied Physics.

Most students in Applied Physics hold appointments as fellows, teaching assistants, or research assistants during the first and second years, and usually as research assistants during subsequent years, including the period of thesis research. The initial assignments of students who begin graduate work with support as research assistants are planned to concur with their interests as closely as they can be identified.

During the summer, teaching fellows and nine-month fellowship appointees are generally appointed as research assistants, and practically all advanced graduate students have stipends either as fellows or as assistants so that their thesis research can be pursued without interruption. Part-time teaching fellowships and summer appointments as research assistants available for fellowship students provide early teaching and research experience.

Degree Programs

Ordinarily graduate students in applied physics enter as candidates for the Ph.D. The Master of Science degree can also be awarded either for two years of formal course study without a thesis plus satisfactory performance on a comprehensive examination, or for a shorter program of formal study accompanied by a master's thesis. There is also a professional degree program leading to a Master of Engineering degree.

M.S. or Ph.D. Degree

ADMISSION REQUIREMENTS. Undergraduate preparation in physics or another physical science, or in an engineering field with strong emphasis on mathematics and modern physics, provides appropriate preparation. Applicants are judged with respect to evidence of quality and capability to benefit by graduate study in Applied Physics. Undergraduate academic achievement, technical experience, and recommendations of teachers and supervisors are carefully considered. Although not required, it is strongly suggested that Graduate Record Examination scores be submitted. The applications of students seeking to return to graduate school after a period of professional employment subsequent to their undergraduate training are welcomed.

FOREIGN LANGUAGE. The Field expects incoming students to have previously studied a modern foreign language at the high school level for three years or at the college undergraduate level for two semesters. For a student without this background, his Special Committee may require proficiency in some modern foreign language as part of the Ph.D. work.

EXAMINATIONS. Every student in the Ph.D. program takes a written qualifying examination, covering the "core" course program, after three semesters of graduate study. Shortly after this, the candidate is given the Ph.D. candidacy examination by his Special Committee. The candidacy examination may be either oral, or written and oral. After it is passed, the candidate's program is expected to emphasize independent research leading to the Ph.D. thesis, and formal courses taken subsequently are usually in areas close to the candidate's research specialty. After the Ph.D. thesis is completed the student is examined on his thesis by his Special Committee.

Professional Degree

The objectives of the four-year engineering physics program are well served by an additional year of advanced study leading to the degree of Master of Engineering (Engineering Physics). The student has the opportunity to master advanced topics in physics and can extend his skill in his chosen engineering specialties. He must carry out an independent project that provides experience in defining objectives, making plans, prosecuting a program, and reporting conclusions. Thus he is expected to develop ability to work independently or cooperatively toward engineering goals without firmly prescribed guide lines other than his own knowledge and judgment.

From the Master's program the student may move into development work, for example, in industry, or he may go on to more advanced graduate study in this or some related Field.

Most of the laboratory facilities for research in the areas described below are made available for the student projects required for the M.Eng. degree. Each project is supervised by a member of the faculty active in the subject.

ADMISSION REQUIREMENTS. (1) For Cornell students: A grade point average of 2.5 or higher in the four-year Field Program in engineering physics will allow admission without petition. (2) For transfer students: Evidence is required that the candidate has the ability and preparation to complete successfully the program of study.

REQUIREMENTS FOR THE PROFESSIONAL DEGREE. (1) An informal study, or project, of at least six credit hours value, which requires individual effort and a formal report, and which may be either experimental or analytical. (2) (a) If the project is experimental, one course in mathematics or applied mathematics; or (b) if it is analytical, one term of advanced laboratory, Physics 510, or an equivalent laboratory course approved by the curriculum committee of the Department. (3) Physics 572, Quantum Mechanics. (4) A minimum of six hours in an engineering course sequence. (5) Chemistry 380, 596 or a new equivalent course to be arranged. (6) A seminar course—a modified version of 8252. One credit hour or more by arrangement. (7) Technical electives to bring the total credit hours to thirty.

Opportunities for Study and Research

Applied theoretical physics: quantum mechanics, statistical physics, applications of irreversible thermodynamics, cooperative phenomena, transport theory, band structures, quantum electronics, atomic basis of hydrodynamics, plasmas, superfluids, molecular theory of liquids, phase stability.

Biophysics: electron microscopy, autoradiography, cell biology, photosynthesis, nuclear techniques in biophysics.

Chemical physics: phase transitions, critical phenomena, chemical kinetics.

Cryogenics: superconductivity, superfluids.

Fluid physics: transport theory, light scattering, critical and collective phenomena, superfluids.

Nuclear and reactor physics: low energy nuclear physics (reactions, isomers, isobaric analog states, fission), neutron physics, nuclear instrumentation (development of detectors and techniques, new applications in engineering and biology), activation analysis, reactor theory, experimental reactor physics.

Optics: lasers, optical coherence and statistical optics, electron optics and high resolution electron microscopy, light scattering and high resolution spectroscopy, x-ray and electron diffraction, scattering and imaging, nonlinear optics, optical properties of solids.

Plasma physics: magnetohydrodynamics, solid state plasmas, shocks and fast reactions, plasma instabilities, energy conversion, controlled nuclear fusion, astrophysical plasmas.

Radiation and matter: solid state electronics at microwave through visible frequencies, radiation damage, excited state atomic and molecular spectroscopy, x-ray and electron scattering.

Solid state physics: crystal defects, diffusion and conduction, dislocation mechanics, flow and fracture, elasticity, internal friction, electronic properties of metals, ionic crystals and semiconductors, superconductivity, ferromagnetism, electron spin resonance, high pressure properties. (For further details, see the description of programs of the Materials Science Center, p. 44.)

Space physics: atmospheric and ionospheric investigations, physical phenomena in astronomy and astrophysics, radio astronomy. (Further details of some programs in this area are given in the description of the Center for Radiophysics and Space Research, p. 42.)

Surface physics: atomistic properties of solid surfaces, interfacial phenomena in liquid and solids, physical electronic behavior, theory and application of low energy electron diffraction and field ionization, physical properties and morphology of surface phases.

Because many of the faculty of the Field of Applied Physics are also members of other fields and research centers, graduate students in Applied Physics can readily cross interdisciplinary boundaries and gain access to extensive research facilities. Additional details about current programs are described in bulletins available from the Field Representative.

Courses of Instruction

Graduate study in Applied Physics is based on a firm knowledge of the fundamentals of physics and mathematics. Although there are no formal course requirements, a "core" program with substitutions or variations is recommended. Because of the policy of interlocking instruction with more specialized groups, the course programs are based primarily on courses administered by other Fields, whose listings should be consulted for course descriptions. An example of the course program of a typical student entering directly from an undergraduate major in physics follows.

First year, first term:

- Physics 510, Advanced Experimental Physics
- Physics 561, Classical Electrodynamics
- Math 415, Mathematical Methods in Physics

First year, second term:

- Physics 572, Quantum Mechanics
- Physics 562, Thermal, Statistical, and Continuum Physics or Chem 596, Statistical Mechanics
- Math 416, Mathematical Methods in Physics

Variations on this core program include substitution of Math 421, 422, or 423 for those with weaker preparation in mathematics, or inclusion of advanced undergraduate-level courses in physics such as Physics 326, 356, 431, 432, or 443 for those whose undergraduate preparation in physics is less extensive. Many students are also able to enter at a more advanced level or carry additional courses. Courses commonly included during either the first or second year are listed below.

- Physics 505–506, Design of Electronic Circuitry
- Physics 574, Intermediate Quantum Mechanics
- Physics 612, Experimental Atomic and Solid State Physics

Physics 510 and 574 are usually available during the summer. The core program assumes that all students will extend their knowledge of quantum mechanics beyond the level of Physics 572, perhaps by study of an application of quantum mechanics in a research specialty.

Specialization at the advanced level is based on the foundation gained in these core courses. Many combinations are possible, and each program is worked out individually. Some of the courses available in various typical specializations are given in the following list, which is not comprehensive. Listings of courses in other fields should be consulted for other topics and for course descriptions.

Nuclear physics:

- Physics 574, Intermediate Quantum Mechanics
- Physics 645, Nuclear and Particle Physics
- Physics 657, Theory of Nuclei
- Nuclear Science 8309, Low-Energy Nuclear Physics
- Nuclear Science 8312 and 8313, Nuclear Reactor Theory I and II
- Nuclear Science 8314, Neutron Transport Theory
- Nuclear Science 8333, Nuclear Reactor Engineering
- Nuclear Science 8351, Nuclear Measurements Laboratory
- Nuclear Science 8352, Advanced Nuclear and Reactor Laboratory

Plasma physics:

Magnetohydrodynamics

- Aerospace Eng 7201, Introductory Plasma Physics
- Aerospace Eng 7202, Introductory Magnetohydrodynamics
- Aerospace Eng 7203, Intermediate Plasma Physics
- Elec Eng 4565 and 4566, Radiowave Propagation I and II

Theoretical plasma physics

- Elec Eng 4561, Introduction to Plasma Physics
- Elec Eng 4564, Advanced Plasma Physics
- Elec Eng 4661, Kinetic Equations

High temperature molecular physics

- Aerospace Eng 7101 and 7102, Advanced Kinetic Theory; Gasdynamics
- Aerospace Eng 7103, Dynamics of Rarefied Gases
- Chem 580, Kinetics of Chemical Reactions
- Chem 598, Selected Topics in Physical Chemistry

Astrophysical plasmas

- Astronomy 520 and 521, Radio Astronomy I and II
- Astronomy 560, Theory of Stellar Structure and Evolution

Quantum electronics:

- Elec Eng 4511, Electrodynamics
- Elec Eng 4514, Microwave Theory
- Elec Eng 4531 and 4532, Quantum Electronics I and II
- Elec Eng 4535 and 4536, Solid State Devices I and II
- Elec Eng 4631 and 4632, The Physics of Solid State Devices

Solid state physics and materials science:

- Physics 635 and 636, Solid State Physics I and II
- Physics 654, Theory of Many-Particle Systems
- Physics 680, Special Topics (in solid state physics)
- Elec Eng 4531 and 4532, Quantum Electronics I and II
- Materials Science 6601, Topics in Thermodynamics and Kinetics
- Materials Science 6602, Phase Transformations
- Materials Science 6603, Crystal Mechanics
- Materials Science 6604, Dislocations
- Materials Science 6605, Electrical and Magnetic Properties of Engineering Materials
- Materials Science 6606, Mechanical Behavior of Materials
- EP 8211, Principles of Diffraction
- EP 8212, Selected Topics in Diffraction
- EP 8262, Physics of Solid Surfaces
- EP 8521, Electron Microscopy and Diffraction

Chem 578, Thermodynamics
Chem 580, Kinetics of Chemical Reactions
Chem 589, X-ray Crystallography
Chem 594, Quantum Mechanics II

Space physics:

Elec Eng 4561, Introduction to Plasma Physics
Elec Eng 4565 and 4566, Radiowave Propagation I and II
Elec Eng 4567, Antennas and Radiation
Astronomy 431, Introduction to Astrophysics
Astronomy 432, Introduction to Space Physics
Astronomy 510, Cosmology and Evolution

(See also listing above, under *Astrophysical plasmas.)*

Courses Administered by Applied Physics

EP 8121 Thermodynamics and Fluid Mechanics. Fall term. Credit three hours.

Classical thermodynamics and applications; compressible one-dimensional flows and shock waves; introduction to fluid mechanics. The general level of sophistication expected is that of the fourth-year student in engineering physics.

EP 8122 Statistical Mechanics and Kinetic Theory. Spring term. Credit three hours. Prerequisite: 8121 or equivalent.

Ensembles and partition functions, ideal quantum and classical gases, imperfect gases, distribution and correlation functions. Random walks and Brownian motion, fluctuations, kinetic theory. At the level of Reif, *Fundamentals of Statistical and Thermal Physics,* or Wannier, *Statistical Physics.*

EP 8133 Mechanics of Particles and Solid Bodies. Fall term. Credit three hours.

Newton's laws, harmonic oscillator. Fourier series and Green's function solutions. Lagrange equations, Hamiltonian formalism, central force motion, orbits, scattering, cross-sections. Many particle dynamics, Lagrangian formulations, Lorentz transformation.

EP 8134 Mechanics of Continua. Spring term. Credit three hours.

Mechanics of continua, equilibrium, propagation of sound waves. Elasticity, torsion, shear, bending stresses.

EP 8155–8156 Intermediate Electrodynamics. Throughout the year. Credit three hours each term. Prerequisite: Physics 234 and 236, and coregistration in Math 421, or consent of the instructor. Course 8155 is prerequisite to 8156. (Replaces Physics 337). Primarily for students of engineering. Mr. Kuckes.

Vector calculus. Electrostatic fields, Laplace and Poisson equations, and boundary value problems, dielectrics, magnetostatic fields, permeable media. Maxwell's equations and wave equations. Waves in free space and in media. Application of Maxwell's equations to wave guides, plasmas, and magnetohydrodynamics. Special relativity. Application of the wave equation to radiation: antennas, scattering of light, reflection, diffraction, polarization, and dispersion. At the level of (for first term) *Foundations of Electromagnetic Theory* by Reitz and Milford, *Introduction to Electromagnetic Theory* by Owen, and (for the second term) *Classical Electromagnetic Radiation* by Marion.

EP 8205 Electrical and Magnetic Properties of Engineering Materials. Fall term. Credit three hours. Prerequisite: Physics 454 or consent of the instructor.

Electrical properties of semiconductors. Metallic alloys. Ferromagnetic materials. Superconductivity. Optical and dielectric properties of insulators and semiconductors. At the level of Kittel, *Introduction to Solid State Physics;* Chikazumi, *Physics of Magnetism;* Lynton, *Superconductivity;* Livingston and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties.*

EP 8211 Principles of Diffraction. Fall term. Credit three hours. Offered jointly with Materials Science and Engineering.

Production of neutrons, x rays, absorption, scattering. Compton effect. Diffraction from periodic lattices, crystal symmetry, single crystal and powder techniques. Fourier methods, thermal vibration and scattering, diffraction from liquids and gases, introduction to dynamical diffraction of x rays and electrons, extinction phenomena and perfect crystals. Selected experiments in diffraction.

EP 8212 Selected Topics in Diffraction. Spring term. Credit three hours. Three lectures. Prerequisite: 8211. Offered jointly with Materials Science and Engineering.

Dynamical diffraction: Ewald-von Laue theory of dynamical diffraction applied to x-rays and electrons. Currently developing theory and application to defects in solids. Phenomena investigated via diffuse scattering: phonons, measurement of dispersion curves, frequency spectrum, Debye temperatures, vibrational amplitudes. Order-disorder phenomena: short- and long-range order, Guinier-Preston zones. Selected topics of current interest related to x-ray, neutron, and electron diffraction, with contributions from several members of the faculty.

EP 8252 Selected Topics in Physics of Engineering Materials. Fall term. Credit one hour. Primarily for candidates for Master of

Engineering (Engineering Physics); others with consent of the instructor.

Seminar-type discussion of special topics such as plastic and rheological properties; dielectric and magnetic behavior; semiconductors; radiation damage, etc. Emphasis is given to the interpretation of the phenomena in light of modern theories in physics of solids and liquids and their impact on the engineering applications. Current literature is included in the assignments.

EP 8262 Physics of Solid Surfaces. Spring term. Credit three hours. A lecture course offered jointly with Materials Science and Engineering.

An introductory critical review of advances in the theory of the solid-state related directly to surface phenomena. Thermodynamics of surface phases, atomistic theory of surfaces, and dynamics of interaction of electrons, ions and atoms with surfaces are considered. Reference is made to application of the theory to surface and interface phenomena in metals, insulators and semiconductors, as much as possible. Presented at the level of *Advances in Solid State Physics,* ed. Seitz and Turnbull.

EP 8601 Physical Approaches to Problems of Photosynthesis. Fall term. Credit three hours. Given in alternate years. Prerequisite: Chem 104 or 108, Math 112, Physics 208, or permission of the instructor.

Emphasis is on physical and photochemical mechanisms and physical experimental approaches. Photosynthetic organisms; their photochemical apparatus, metabolic pathways, and mechanisms for energy conversion. Descriptive introduction to the physics of excited states in molecules and molecular aggregates. Optical and photochemical properties of chlorophyll, and of the living photosynthetic tissue. Contemporary investigations of the photosynthetic mechanism. At the level of Clayton, *Molecular Physics in Photosynthesis.*

EP 8603 General Photobiology. Fall term. Credit three hours. Prerequisite: Chem 104 or 108, Math 112, Physics 208, or permission of the instructor. Given in alternate years.

A survey of systems of current interest in photobiology, including photosynthesis, bioluminescence, vision, photoperiodism, and the action of ultraviolet light on nucleic acids. Physical concepts and methodologies are emphasized.

Astronomy and Space Sciences

Faculty
Ralph Bolgiano, Neil M. Brice, John P. Delvaille, Frank D. Drake, Donald T. Farley, Thomas Gold, Kenneth I. Greisen, Martin O. Harwit, James R. Houck, Frederick Jelinek, Richard L. Liboff, George H. Morrison, Brian T. O'Leary, Edwin L. Resler, Jr., Henri S. Sack, Carl Sagan, Edwin E. Salpeter, Ravindra N. Sudan, Yervant Terzian, Robert Wagoner

Field Representative
Carl Sagan, 302 Space Sciences Building

MAJOR AND MINOR SUBJECTS

Astronomy
Astrophysics
Magnetohydrodynamics
Planetary Studies
Radiophysics
Space Sciences (General)

ADMISSION REQUIREMENTS. General admission requirements are described on p. 7 of this *Announcement.* Students may come to this Field with a strong background in astronomy, electrical engineering, engineering physics, mathematics, or physics. Submission of scores obtained on the Graduate Record Examination is optional but often is of great help in admitting outstanding students from less known institutions, or from colleges which previously have not had students attend Cornell.

Students wishing to transfer into the Field of Astronomy and Space Sciences from other fields at Cornell should apply for admission early in February. Their applications will then be considered together with those of new applicants from outside the University.

DEGREE REQUIREMENTS. Students are expected to complete either Mathematics 415–416, or the 1180–1182 applied mathematics sequence of the Field of Theoretical and Applied Mechanics. Four astronomy courses at the 500 level and Physics 561, 562, and 572 are also required. An additional course in applications of quantum mechanics is strongly recommended for those who go on to thesis work in astrophysics. Finally, all students should take Physics 510 or should have had an equivalent amount of laboratory experience.

There is no language requirement for the Master's degree. For the Ph.D. degree, the student must demonstrate proficiency in one of the following: French, German, or Russian.

Examinations required by the Graduate School are described on p. 11 of this *Announcement.* In addition, the Field expects the student to pass a qualifying examination at the beginning of his second year of graduate study.

The major and both minor subjects for the doctorate should not all be chosen in this Field.

RESEARCH OPPORTUNITIES. Members of the staff are particularly interested in directing graduate research in the following subjects.

Astronomy and astrophysics: cosmic rays, cosmology, dynamics of the interstellar gas, solar system magnetohydrodynamics, theory of stellar structure, stellar evolution, nuclear processes in stars, stellar statistics.

Atmospheric and ionospheric radio investigations: dynamics of the atmosphere and ionosphere; incoherent electron scattering; study of refraction, scattering, attenuation due to the inhomogeneous nature of the troposphere and ionosphere; theory and observation of propagation of radiowaves in ionized media such as the ionosphere.

Radio astronomy: distribution and classification of radio sources; radar investigations of the moon and planets; solar radio observations; studies of gaseous nebulae; radio-galaxies, quasars, pulsars.

Space vehicle instrumentation: instrumentation relating to lunar and planetary exploration; magnetic field measurements; tenuous gas and particle flux measurements; infrared observations from rockets.

Infrared astronomy: observational and theoretical studies of dust clouds, ionized hydrogen regions and cosmic background; development of novel spectrometric techniques.

Lunar studies: simulations of the lunar surface; analysis of samples returned by the first Apollo lunar landing crews; spacecraft investigations of the moon; studies of the lunar interior and origin.

Planetary studies: observational, theoretical, and laboratory studies of planetary atmospheres and surfaces: for example, seasonal changes and elevation differences on Mars, structure of the Venus atmosphere. Spacecraft investigations, especially forthcoming Mariner missions. Exobiology, including the production of organic molecules in simulated planetary environments.

Graduate students in this Field may be connected with the Cornell University Center for Radiophysics and Space Research. Many members of the faculty listed above are members of this Center, which possesses or is planning important facilities for geophysical and solar system investigations both by radio methods and by space vehicle instrumentation. The Center operates an Infrared Laboratory, a Lunar Laboratory, and the Laboratory for Planetary Studies. Center personnel use large optical telescopes in the American southwest, and Cornell is a charter member of the consortium organizing the proposed 150-inch telescope of New York State Universities.

Students may also be connected with the Cornell-operated Arecibo Observatory, Arecibo, Puerto Rico, the largest radiotelescope in the world. Graduate students in this field often conduct their thesis research while resident at Arecibo.

The Cornell-Sydney University Astronomy Center, an international cooperative venture, provides students and faculty members of the two universities with an opportunity to work together in the field. The Sydney University facilities include the Criss-Cross and Mills Cross radio telescopes, the stellar intensity interferometer, detectors for very high energy cosmic rays, and plasma and nuclear physics laboratories. Further details of these organizations and facilities can be obtained by writing to the Secretary, Cornell University Center for Radiophysics and Space Research, Space Sciences Building. See also pp. 42 and 43.

Courses

431 Introduction to Astrophysics. Fall term. Credit three hours. Prerequisite: Physics 225, 226, and 303 or equivalent. Mr. Harwit.

Dynamics of planetary and stellar systems; stellar structure and evolution; binary, variable and peculiar stars; nuclear synthesis in stars; stellar atmospheres; abundance of the chemical elements.

432 Introduction to Space Physics. Spring term. Credit three hours. Prerequisite: 431 or consent of the instructor. Mr. Harwit.

Interstellar dust and gas; evolution of the Stromgren sphere; star formation; interstellar magnetic fields, cosmic rays and radio emission; interplanetary gas and dust; comets, meteorites, and micrometeorites.

509 Gravitational Theory. Fall term. Credit three hours. Prerequisite: Physics 561 and 562, or consent of the instructor. Mr. Wagoner.

Fundamental properties of the gravitational interaction; Riemannian geometry and tensor analysis; derivation of various theories, with emphasis on general relativity; discussion of observational tests and other solutions of astrophysical interest.

510 Cosmology and Evolution. Spring term. Credit three hours. Offered on sufficient demand. Prerequisite: 509 or consent of the instructor. Messrs. Gold and Wagoner.

Fundamental observations and principles of cosmology. Discussion of various models and observational tests. Relativistic astrophysics. Structure and evolution of galaxies and quasi-stellar objects.

520 Radio Astronomy I. Fall term. Credit three hours. Messrs. Drake and Terzian.

Radio astronomy telescopes and electronics; preferred observing procedures and data analysis; concepts of aperture synthesis; physical mechanisms of radio emission; radio and radar studies of the solar system; physical nature of the sun, moon, and planets as deduced from radio sources.

521 Radio Astronomy II. Spring term. Credit three hours. Prerequisite: 520. Messrs. Drake and Terzian.

Thermal and nonthermal radiation from the galaxy; supernova remnants; relation of galactic emission to cosmic rays; galactic 21-cm. emission; galactic structure and kinematics as inferred from radio observations; radio emission from normal and abnormal galaxies; quasi-stellar radio sources; pulsars; physical theories of the quasi-stellar sources and abnormal radiogalaxies.

530 Nuclear Astrophysics. Spring term. Credit three hours. Prerequisite: Physics 572 or consent of the instructor. Given in alternate years. Mr. Wagoner.

Discussion of abundances and other observations relevant to the question of the origin of the elements. Derivation of nuclear reaction rates. Stellar energy generation and synthesis processes. Big bang and other high-temperature synthesis processes.

560 Theory of Stellar Structure and Evolution. Fall term. Credit three hours. Prerequisite: good physics background. Given upon sufficient demand (usually in alternate years). Staff.

Summary of observational facts; dimensional analysis; nuclear reactions in stars; models for static and evolving stars; very massive objects and general relativity; white dwarfs and neutron stars.

570 Physics of the Planets. Fall term. Credit three hours. Prerequisite: good physics background. Given upon sufficient demand (usually in alternate years). Mr. Sagan.

Physics and chemistry of planetary atmospheres, surfaces and interiors; the roles of convective, conductive and radiative transport; optical, infrared, radio, radar and spaceprobe information; applications to exobiology and to the earth as a planet.

633 Infrared Astronomy. Fall term. Credit three hours. Prerequisite: consent of the instructor. Given in alternate years. Messrs. Harwit and Houck.

Techniques of modern infrared astronomical observation; emission mechanisms of cosmic infrared radiation; infrared observations of planets, stars, nebulae, galaxies, and cosmic background radiation.

640 Advanced Study and Research. Either term. Credit one to four hours a term. Prerequisite: advanced standing in astronomy and consent of the instructor. Staff.

Upon sufficient demand, seminars will be arranged from time to time in topics not currently covered in regular courses. Typical subjects are high energy particles in astronomy and geophysics.

650 Interstellar Matter. Fall term. Credit three hours. Mr. Terzian.

The study of emission, reflection, and dark nebulae; interstellar absorption and reddening; planetary nebulae, novae and supernovae shells; neutral hydrogen distribution in the galaxy; interstellar gas dynamics.

671 Special Problems in Planetary Astronomy. Spring term. Credit two hours. Prerequisite: 570. Mr. Sagan.

672 Seminar in Planetary Studies. Spring term. Credit two hours. Prerequisite: 570. Mr. Sagan.

Courses Administered by Other Fields

Electrical Engineering

4551–4552 Upper Atmosphere Physics I and II.

4561 Introduction to Plasma Physics.

4564 Advanced Plasma Physics.

4565–4566 Radiowave Propagation I and II.

4567 Antennas and Radiation.

Theoretical and Applied Mechanics

1772 Space Flight Mechanics.

1773 Mechanics of the Solar System.

Chemical Engineering

Faculty
Kenneth B. Bischoff, George G. Cocks, Victor H. Edwards, Robert K. Finn, Peter Harriott, Jay E. Hedrick, Jean P. Leinroth, Jr., Ferdinand Rodriguez, George F. Scheele, Julian C. Smith, Raymond G. Thorpe, Robert L. Von Berg, David M. Watt, Jr., Herbert F. Wiegandt, Charles C. Winding, Robert York

Field Representative
Charles C. Winding, 124 Olin Hall

MAJOR AND MINOR SUBJECTS
Biochemical Engineering
Chemical Engineering, General
Chemical Microscopy
Chemical Processes and Process Control
Materials Engineering
Nuclear Process Engineering

To qualify for admission, a student must have completed satisfactorily the equivalent of the fundamental work required by an accredited curriculum in chemical engineering. Outstanding students who have received a baccalaureate degree with a major in chemistry will also be considered; they will normally require an extra year of residence to make up work in engineering fundamentals.

Chemical Engineering, General, is required of all students, either as a major or as a minor. Ph.D. candidates are required to select one minor within and one minor outside the Field. M.S. candidates may choose a minor within or outside the Field. There is no language requirement for the M.S. or the Ph.D. degree. Each M.S. candidate must pass an oral examination on his major and minor subjects and on his thesis. Two examinations are required before a student is designated as a Ph.D. candidate. On recommendation of the faculty, a student will be admitted to the written Field examination. When this examination has been passed to the satisfaction of the faculty of the Field, the student must take an oral comprehensive admission to candidacy examination administered by his Special Committee. After the thesis has been completed, an oral final examination, administered by the Special Committee and covering the thesis and related topics, must be taken.

Candidates are expected to pursue a course of study and research that will give them a deeper comprehension of the basic and applied sciences and will develop initiative, originality, and creative ability. To achieve this goal the student participates in graduate courses and seminars and must complete an original, individual investigation for a thesis. Theses may involve either experimental research or special projects in such subjects as design, economics, and mathematical analysis. Specific programs are planned to fit the objectives of the student, and to develop original thinking. An arbitrarily fixed series of courses is not required, but each student is expected to acquire a strong background in applied mathematics, chemical processes, rate and mass transfer processes, reaction kinetics, and thermodynamics. Outside minor subjects may be chosen from a wide variety of other Fields.

RESEARCH OPPORTUNITIES. Fluid dynamics, heat transfer, mass transfer, reaction kinetics, stage processes, and thermodynamics may be regarded as the fundamentals of chemical engineering. The Cornell staff is actively working on or has interests in many such projects. Although particular projects actively in progress are continually changing, some recent, specific research interests of staff members follow.

Kenneth B. Bischoff: chemical reaction kinetics and interactions with diffusional processes, catalyst deactivation, biochemical and medical biological engineering.

George G. Cocks: microscopy, properties of materials, solid state chemistry, crystallography.

Victor H. Edwards: kinetics and process control in fermentation.

Robert K. Finn: continuous fermentation, agitation and aeration, processing biochemicals, electrophoresis, microbial conversion of hydrocarbons.

Peter Harriott: chemical kinetics and reactor design, process control, diffusion in membranes and porous solids.

Jay E. Hedrick: economic analyses and forecasts.

Jean P. Leinroth, Jr.: reaction kinetics, thermodynamics, desalination of sea water.

Ferdinand Rodriguez: polymerization, rheology of polymer systems, gel permeation chromatography.

George F. Scheele: hydrodynamic stability, coalescence, fluid mechanics of liquid drops and jets, convection-distorted flow fields.

Julian C. Smith: conductive transfer processes, flow of granular solids, heat transfer, mixing.

Raymond G. Thorpe: phase equilibria, fluid flow, kinetics of polymerization.

Robert L. Von Berg: liquid-liquid extraction, reaction kinetics, effect of radiation on chemical reactions.

David M. Watt, Jr.: heterogeneous catalysis, combustion.

Herbert F. Wiegandt: crystallization, petroleum processing, saline-water conversion, direct contact heat transfer.

Charles C. Winding: degradation of polymers, polymer compounding, filler-polymer systems, differential thermal analysis.

Robert York: molecular sieves; chemical market analyses; process development, design, and evaluation; chemical economics.

PROFESSIONAL DEGREE. The Master of Engineering degree is a professional engineering degree. Admission to the Master of Engineering (Chemical) degree program is open to persons who have been granted a Bachelor's degree or the equivalent, and whose background indicates that they can profitably study the advanced courses offered by the School of Chemical Engineering. The purpose of this program is to offer study in depth in both comprehensive and specialized chemical engineering subjects and to prepare students for professional careers in advanced engineering practice.

Courses

5105 Advanced Chemical Engineering Thermodynamics. Fall term. Credit three hours. Three lectures. Mr. Von Berg.

Application of the general thermodynamic method to advanced problems in chemical engineering.

5106 Reaction Kinetics and Reactor Design. Fall term. Credit three hours. Three lectures. Mr. Finn.

A study of chemical reaction kinetics and principles of reactor design for chemical processes.

5107 Reactor Design. Fall term. Credit three hours. Three lectures. Mr. Harriott.

Effects of heat transfer, diffusion, and nonideal flow on reactor performance. Optimum design for complex reactions.

5108 Colloidal and Surface Phenomena. Fall term. Credit three hours. Mr. Finn.

Lectures, demonstrations, and problems in the physics and chemistry of small particles and surface films.

5109 Advanced Chemical Kinetics. Spring term. Credit three hours. Three lectures. Prerequisite: 5106 or equivalent. Mr. Watt.

Reaction rate theory and application to complex reaction mechanisms; adsorption phenomena and application to heterogeneous catalytic reactions.

5161 Phase Equilibria. Fall term. Credit three hours. Three lectures. Mr. Thorpe.

A detailed study of the pressure-temperature-composition relations in binary and multicomponent heterogeneous systems where several phases are of variable composition.

5505–5506 Advanced Transport Phenomena. Fall and spring term. Credit four hours a term. Messrs. Scheele, Harriott, and Smith.

An integrated treatment of momentum, mass and heat transfer.

5510, 5512 Numerical Methods in Chemical Engineering I and II. Fall and spring terms. Credit three hours a term. Mr. Leinroth.

Application of computer methods to the solution of complex chemical engineering problems.

5605, 5606, 5607, 5608 Design Projects. Fall and spring terms. Credit variable. Staff.

Individual projects involving the design of chemical processes and plants.

5609 Properties of Particles and Dispersions. Fall term. Credit three hours. Three lectures. Prerequisite: 5304 or consent of the instructor. Mr. Smith.

Characteristics of particulate solids; mixing; size change; fluidized systems. Production and properties of dispersions of bubbles, drops, and particles.

5621 Process Design and Economics. Fall term. Credit six hours. Mr. York.

Methods for estimating capital and operating costs. Performances, selection, design, and cost of process equipment. Market research and surveys.

5622 Process and Plant Design. Spring term. Credit six hours. Continuation of 5621. Mr. York.

Process design, including reactors, process equipment, and separating systems. Layout and model of process units. Plant location, design, and layout. Cost estimates and project evaluation.

5635 Marketing of Chemical Products. Fall term. Credit three hours. Three lectures. Mr. Hedrick.

Examination of marketing activities, organizations, and costs in the distribution of chemicals. A market research project is required.

5636 Economics of the Chemical Enterprise. Spring term. Credit three hours. Three lectures. Mr. Hedrick.

Research economics; feasibility studies; information services; venture analysis; depreciation and amortization; planning.

5642 Development Economics. Spring term. Credit three hours. Mr. York.

Planning, evaluation, and management of development activities in the process industries as related to research, processing, new products, markets, and long-range growth.

5717 Process Control. Spring term. Credit three hours. Two lectures, one laboratory. Mr. Harriott.

Dynamic response of processes and control instruments. Use of frequency response analysis, Laplace transforms, and electronic analogs to predict the behavior of feedback control systems.

5741 Petroleum Refining. Spring term. Credit three hours. Three lectures. Mr. Wiegandt.

A critical analysis of the processes employed in petroleum refining.

5742 Polymeric Materials. Fall term. Credit three hours. Three lectures. Mr. Rodriguez.

Chemistry of polymerization reactions, manufacture and properties of synthetic resins, fibers, plastics, and rubbers.

5743 Properties of Polymeric Materials. Spring term. Credit three hours. Prerequisite: 5742. Mr. Rodriguez.

Mechanical, electrical, and optical properties of polymers. Phenomenological aspects and molecular theories of non-Newtonian flow, viscoelasticity, and ultimate tensile properties.

5745 Analysis of Polymeric Processes. Fall term. Credit three hours. Three lectures. Prerequisite: 5742. Mr. Hedrick.

Technical and economic evaluations of the principal processes used in manufacture of resins, plastics, and elastomers, including analyses of raw materials, reactor systems, product preparation, and problems in distribution and marketing.

5746 Case Studies in the Commercial Development of Chemical Products. Spring term. Credit three hours. Three lectures. Mr. Hedrick.

Detailed analysis of specific cases involving the development of new chemical products. Emphasis is given to planning activities, research justification, and market forecasting. Profitability calculations and projections are required.

5748 Fermentation Engineering. Spring term. Credit three hours. Two lectures, one recitation. Mr. Finn.

An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

5749 Industrial Microorganisms. Fall term. Credit one hour. One lecture. Mr. Finn.

A brief introductory course in microbiology for students with a good background in chemistry.

5752 Polymeric Materials Laboratory. Fall term. Credit two hours. One laboratory. Prerequisite: 5742. Mr. Rodriguez.

Experiments in the formation, characterization, fabrication, and testing of polymers.

5760 Nuclear and Reactor Engineering. Spring term. Credit two hours. Two lectures. Mr. Von Berg.

Fuel processing and isotope separation, radioactive waste disposal, fuel cycles, radiation damage, biological effects and hazards, shielding, radiation chemistry.

5761 Topics in Bioengineering. Either term. Credit two hours. Two lectures. Prerequisite: 5748 or consent of the instructor. Mr. Edwards.

Analysis of transport phenomena, reaction kinetics, process dynamics and control, and optimization in biological systems.

5851 Chemical Microscopy. Spring term. Credit three hours. One lecture, two laboratories. Mr. Cocks.

5857 Electron Microscopy. Fall term. Credit two hours. One lecture, one laboratory. Prerequisite: a course in microscopy or special permission. Mr. Cocks.

5859 Advanced Chemical Microscopy. Either term on demand. Credit variable. Mr. Cocks.

Laboratory practice in special methods and special applications of chemical microscopy.

5900 Seminar. Fall and spring terms. Credit one hour.

General chemical engineering seminar required of all graduate students majoring in the Field.

5903 Seminar in Biochemical Engineering. Spring term. Credit one hour. Messrs. Edwards and Finn.

Chemistry

Faculty

A. C. Albrecht, S. H. Bauer, A. T. Blomquist, C. A. Brown, J. M. Burlitch, W. D. Cooke, V. du Vigneaud, E. L. Elson, R. C. Fay, M. E. Fisher, G. A. Fisk, J. H. Freed, M. J. Goldstein, G. G. Hammes, J. L. Hoard, R. Hoffmann, R. E. Hughes, E. S. Kostiner, F. A. Long, G. M. Loudon, F. W. McLafferty, J. Meinwald, W. T. Miller, G. H. Morrison, H. Muxfeldt, R. A. Plane, R. F. Porter, R. R. Rye, H. A. Scheraga, F. R. Scholer, M. F. Semmelhack, M. J. Sienko, D. A. Usher, B. Widom, C. F. Wilcox, Jr.

Professor-at-Large

M. Eigen

Field Representative
W. T. Miller, 350 Baker Laboratory

MAJOR AND MINOR SUBJECTS
Analytical Chemistry
Bioorganic Chemistry
Biophysical Chemistry
Inorganic Chemistry
Organic Chemistry
Physical Chemistry
Theoretical Chemistry

ADMISSION REQUIREMENTS. Applicants for the M.S. or Ph.D. program in chemistry should have the equivalent of an A.B. degree with a major in chemistry, including courses in general chemistry, mathematics, organic chemistry, physical chemistry, physics, and qualitative and quantitative analysis. In admitting students, emphasis is placed on quality of performance and promise for research as judged by those best acquainted with applicants. Unusually promising students may be admitted with deficiencies in undergraduate training, but will have to take work designed to make up the deficiencies and may require more than the usual period of residence.

AIMS AND OPERATIONS OF THE FIELD. The program of graduate study in the Field of Chemistry is designed to give a broad training in the fundamental knowledge of chemistry and in methods of research. A graduate student will ordinarily pursue these objectives by taking advanced courses, by participation in organized and informal seminars and discussions with his associates and faculty members, and by carrying out and reporting on a research project in his major subject. Special opportunities are provided by (1) the Materials Science Center at Cornell (see pp. 44), which supports several research assistantships for graduate students in chemistry, and (2) a National Institutes of Health Training Grant which similarly provides trainee stipends for work in bioorganic and biophysical chemistry. In addition to the courses in chemistry, attention is directed to courses in biochemistry, chemical engineering, mathematics, and physics. Graduate students are encouraged to carry on research during the summer, and a number of Summer Research fellowships are available. Upon completion of their study program, graduates normally go out to positions in research laboratories or to positions involving teaching and research.

Entering graduate students are required to register with the Department of Chemistry on the registration days at the beginning of their first term. These students will consult with the chairman of the Department and with professors composing their temporary Special Committees.

Proficiency tests in analytical, inorganic, organic, and physical chemistry will be required of all entering M.S. or Ph.D. candidates. These tests are given a few days before registration for the fall term; each is about two and one-half hours long and covers material normally presented in elementary courses in the subjects listed above. Test results will be used to help the student's Special Committee plan his program. While the results will not be considered in the usual sense of "passing" or "failing," low marks in one or more of the tests may require enrollment in elementary courses.

Two years of satisfactory performance as a teaching assistant are required of all students who are candidates for an advanced degree.

LANGUAGE REQUIREMENTS. There is no uniform language requirement for either the Ph.D. or M.S. degree. However, organic chemistry majors are required to pass German or, with permission, Russian. In addition, individual major advisers in other chemical disciplines may require a language of their students.

EXAMINATIONS. In addition to the regular admission to doctoral candidacy examination and final examination (thesis defense), those students majoring in organic chemistry are required to pass eight cumulative examinations which are offered approximately monthly throughout the year. Students making normal progress toward the Ph.D. will typically take sixteen such examinations.

MINORS FOR STUDENTS IN OTHER FIELDS. A graduate student who desires to take a minor subject in Chemistry with a major subject from some other Field will be required to offer or acquire a satisfactory background for advanced work. This will ordinarily consist of an introductory course in general chemistry and of intermediate courses prerequisite to advanced work in the minor subject in Chemistry.

Specific inquiries from prospective graduate students are welcomed and should be addressed to the Field Representative or to any member of the faculty. Applications for teaching fellowships or research assistantships should be addressed to the Field Representative. A brochure entitled *Graduate Work in Chemistry at Cornell* is available from the Field Representative.

Courses

411 Inorganic Chemistry Laboratory. Fall term. Credit four hours. Prerequisite or parallel course: a basic course in physical chemistry or consent of the instructor.

[457 Advanced Organic-Analytical Laboratory. Spring term. Credit four hours. Prerequisite: basic courses in organic and analytical chemistry, or consent of the instructor. Not offered 1971–72.]

465 Advanced Organic Chemistry. Throughout the year. Credit four hours a term. Prerequisite: basic courses in organic and physical chemistry, or consent of the instructor.

A survey of the simplest organic reactions within the framework of a mechanistic approach. The principal aim is to provide the student with the skills and background needed to predict the reactivity patterns and stereochemical preferences of new molecules in a variety of experimental environments. Qualitative applications of statistical thermodynamics and molecular orbital theory will be illustrated by readings from the current research literature.

466 Synthetic Organic Chemistry. Spring term. Credit four hours. Primarily for graduate students and upperclass undergraduates. Prerequisite: 465 or consent of the instructor.

Modern techniques of syntheses; applications of organic reaction mechanisms to the problems encountered in rational multistep syntheses, with particular emphasis on newer developments.

468 Chemical Aspects of Biological Processes. Fall term. Credit four hours. Prerequisite: basic courses in organic and physical chemistry.

Bioenergetics, metabolic pathways, origins of life. This course forms the chemical basis for the graduate program in molecular biology.

470 Chemical Ecology (Biological Sciences 466). Spring term. Credit two hours. Prerequisite: basic courses in organic chemistry and biological science, or consent of the instructor. Offered in even-numbered years.

Ecological and evolutionary significance of chemical interactions between organisms. Summary of key processes in regulation of natural populations. Survey of major classes of natural products with emphasis on appropriate analytical techniques. Chemical adaptations for reproduction, defense, habitat selection, dispersal, feeding efficiency, and competition in animals, plants, and microorganisms. Choice of adaptive strategy in relation to energy flow. Practical applications of chemical ecology.

481 Physical Chemistry III. Fall term. Credit four hours. Prerequisite: a basic course in physical chemistry.

A discussion of advanced topics in physical chemistry, including an introduction to the principles of quantum theory and statistical mechanics, atomic and molecular spectra, and elementary valence theory.

505–506 Advanced Inorganic Chemistry. Throughout the year. Credit four hours a term. Prerequisite: basic courses in physical chemistry, or consent of the instructor; 505 is prerequisite to 506.

First term: introduction to group theory and its application to hybrid orbitals, molecular orbitals and molecular vibrations of small molecules. Recent advances in the structure, bonding and chemical properties of selected nontransition elements. Second term: crystal field theory, ligand field theory, magnetic and optical properties, thermodynamic cycles of aqueous ions, systematics of transition-metal chemistry.

515–516 Selected Topics in Advanced Inorganic Chemistry. Throughout the year. Credit two hours a term. Students may register for either term separately. Prerequisite: a basic course in physical chemistry. S–U grades only.

Topics are varied from year to year.

525 Advanced Analytical Chemistry I. Fall term. Credit four hours. Prerequisite: a basic course in physical chemistry.

The application of molecular spectroscopy to chemical problems. Topics discussed include ultraviolet, infrared, NMR, Raman, and mass spectroscopy.

[**527 Advanced Analytical Chemistry II.** Spring term. Credit four hours. Prerequisite: a basic course in physical chemistry. Offered in alternate years. Not offered 1971–72.

Modern analytical methods, including electron spectroscopy, mass spectrometry (spark source, high resolution), activation analysis, methods applicable to macromolecules, and applications of on-line computers.]

528 Advanced Analytical Chemistry III. Spring term. Credit three hours. Prerequisite: a basic course in physical chemistry. Primarily for graduate students. Offered in alternate years. Offered 1971–72.

Modern analytical methods, including electroanalytical, diffraction, and separation techniques; ultratrace analysis; Mössbauer and Fourier spectroscopy; microscopy.

565 Physical Organic Chemistry I. Fall term. Credit four hours. Prerequisite: 465–466 or consent of the instructor.

Mechanisms of organic reactions, with particular attention paid to the properties of reactive intermediates: carbonium ions, carbanions, free radicals, carbenes, and electronically excited molecules.

566 Physical Organic Chemistry II. Spring term. Credit three hours. Prerequisite: 565 or consent of the instructor.

Quantitative aspects of organic chemistry.

570 Selected Topics in Organic Chemistry. Fall term. Credit three hours. Prerequisite: 465–466 or consent of the instructor. S–U grades only.
Topics will be varied from year to year.

572 Organic Mechanisms and Enzyme Catalysis. Spring term. Credit four hours. Prerequisite: basic organic chemistry and a course in general biochemistry.
Enzymes, coenzymes and model systems.

574 Chemistry of Natural Products. Fall term. Credit three hours. Prerequisite: 456 or 457, and 465–466.
Particular attention will be devoted to methods of structure determination and synthesis as applied to selected terpenes, steroids, alkaloids, and antibiotics.

577 Chemistry of Nucleic Acids. Fall term. Credit four hours. Prerequisite: basic courses in organic and physical chemistry. S–U grades only.
Properties, synthesis, and reactions of nucleic acids.

578 Thermodynamics. Spring term. Credit four hours. Prerequisite: a basic course in physical chemistry.
Development of the general equations of thermodynamics from the first and second laws. Applications to the study of physico-chemical equilibria in gases, liquids, solids, and liquid solutions. Problems.

580 Kinetics of Chemical Reactions. Fall term. Credit four hours. Prerequisite: 481 and 578, or consent of the instructor.
Principles and theories of chemical kinetics; special topics including fast reactions in liquids, enzymatic reactions, shock tubes, and molecular beams.

582 Special Topics in Molecular Biology. Spring term. Credit four hours. Prerequisite: 468 or consent of the instructor. S–U grades only.
Topics will be varied from year to year.

586 Physical Chemistry of Proteins. Spring term. Credit four hours. Prerequisite: a basic course in physical chemistry.
Chemical constitution, molecular weight, and structural basis of proteins; thermodynamic, hydrodynamic, optical, and electrical properties; protein and enzyme reactions; statistical mechanics of helix-coil transition in biopolymers; conformation of biopolymers.

589 X-Ray Crystallography. Fall term. Credit four hours. Prerequisite: Physics 322 or consent of the instructor. Offered only when sufficient registration warrants.
Space groups, reciprocal lattices, three-dimensional diffraction, interpretation of x-ray diffraction data, structure determination by Fourier synthesis.

593 Quantum Mechanics I. Fall term. Credit four hours. Prerequisite: an advanced course in physical chemistry, and coregistration in Physics 431 and Math 421, or consent of the instructor.
Schrödinger's equation, wave packets, uncertainty principle, WKB theory. Matrix mechanics, orbital and spin angular momentum, exclusion principle, perturbation theory, variational principle, Born-Oppenheimer approximation. At the level of Bohm, *Quantum Theory.*

594 Quantum Mechanics II. Spring term. Credit four hours. Prerequisite: 593 or its equivalent and coregistration in Physics 432 and Math 422, or consent of instructor.
Time-dependent phenomena in quantum mechanics and interaction with radiation. Group theory and applications. Topics in molecular quantum mechanics. At the level of Tinkham, *Group Theory and Quantum Mechanics.*

596 Statistical Mechanics. Spring term. Credit four hours. Prerequisite: 593 or equivalent is desirable but not required.
Ensembles and partition functions. Thermodynamic properties of ideal gases and crystals. Third law of thermodynamics, equilibrium constants, vapor pressures, imperfect gases, and virial coefficients. Distribution and correlation functions. Lattice statistics and phase transitions. Bose-Einstein and Fermi-Dirac ideal gases. Maxwell theory of viscosity and heat conduction. At the level of Hill, *Statistical Thermodynamics.*

598 Selected Topics in Physical Chemistry. Fall term. Credit two hours. S–U grades only.
Topics are varied from year to year.

600 General Chemistry Seminar. Throughout the year. No credit. Normally attended by all students other than organic majors.
A series of talks representative of all fields of current research interest in chemistry, other than organic chemistry, given by research associates, faculty members, and distinguished visitors.

601–602 Introductory Graduate Seminar in Analytical, Inorganic, and Physical Chemistry. Throughout the year. No credit. Required of all first-year graduate students majoring in chemistry and molecular biology. S–U grades only.
Weekly seminars on contemporary topics prepared and presented by first-year graduate students. Attention given to details of selecting, preparing, and presenting a given topic. Group preparation and participation emphasized.

650–651 Graduate Seminar in Organic Chemistry. Throughout the year. No credit. Normally attended by all organic majors.

A series of talks representative of all fields of current research interest in organic chemistry, given by research associates, faculty members, and distinguished visitors.

700 Baker Lectures. Fall term: Michael Szwarc, Syracuse University. Spring term: To be announced.

Civil Engineering

Faculty
Vaughn C. Behn (Sanitary), Donald J. Belcher (Aerial Photographs), Wilfried Brutsaert (Hydrology), Leonard B. Dworsky (Water Resources, Pollution Control), Louis M. Falkson (Applied Welfare Economics), Gordon P. Fisher (Environmental Systems), Richard H. Gallagher (Structures), Charles D. Gates (Sanitary), Peter Gergely (Structures), Donald P. Greenberg (Structures), William L. Hewitt (Subgrades, Pavements), Alonzo W. Lawrence (Sanitary), Ta Liang (Aerial Photographs, Physical Environment), James A. Liggett (Hydraulics), Raymond C. Loehr (Sanitary), Daniel P. Loucks (Water Resources Engineering), Walter R. Lynn (Environmental Systems), George B. Lyon (Surveying), William McGuire (Structures), Arthur J. McNair (Geodesy-Photogrammetry), Arnim H. Meyburg (Urban Transportation and Planning), Arthur H. Nilson (Structures), Teoman Peköz (Structural Engineering Experimental Research), Charles S. ReVelle (Environmental Systems), Dwight A. Sangrey (Soils), Robert G. Sexsmith (Structures), Floyd O. Slate (Engineering Materials), Shaler Stidham, Jr. (Environmental Systems), Richard N. White (Structures), George Winter (Structures)

Field Representative
Arthur H. Nilson, 365 Hollister Hall

MAJOR SUBJECTS

Aerial Photographic Studies* (M.S. only)
Environmental Systems Engineering
Geodetic and Photogrammetric Engineering
Geotechnical Engineering
Hydraulics and Hydrology
Sanitary Engineering
Structural Engineering
Transportation Engineering
Water Resource Systems (Ph.D. only)

MINOR SUBJECTS. All of the major subjects except Water Resource Systems can be taken as minor subjects at either the M.S. or Ph.D. level. In addition, Structural Mechanics is an approved minor subject.

PROFESSIONAL DEGREE. The School of Civil Engineering also offers the professional degree of Master of Engineering (Civil) which is intended primarily for those students who intend to enter engineering practice and who do not intend to obtain the doctorate. Work for this degree consists of courses which are designed to give the student a background in the elements of engineering design as well as a broad fundamental base. Those choosing the professional degree may concentrate their studies in one or more of the subareas of civil engineering listed below. In addition, a program in construction engineering is available.

ADMISSION REQUIREMENTS. To be considered for admission to graduate study in the Field of Civil Engineering, an applicant must hold a baccalaureate degree granted by a faculty or university of recognized standing or have completed studies equivalent to those required for a baccalaureate degree at Cornell. Although the Graduate Record Examination is not required, applicants are urged to submit results of this examination with their application.

FINANCIAL AID. Fellowships, traineeships, research assistantships, teaching fellowships, and laboratory assistantships are available.

LANGUAGE REQUIREMENTS. There is no foreign language requirement imposed by the Field of Civil Engineering; however, for Ph.D. candidates, individual Departments or Special Committees within the Field may require proficiency in one or more languages. A reading knowledge of one foreign language, usually French, German, or Russian, is commonly required.

EXAMINATIONS. Civil Engineering requires a final comprehensive examination for the M.S. degree. For the Ph.D. degree the student must take (a) a qualifying examination shortly after receiving his M.S. or, if he comes to Cornell with an M.S., shortly after arrival; (b) a general examination on subject matter taken approximately at the time he completes his course work; and (c) a final examination in which he defends his dissertation.

Additional information on specific programs is available by writing to the Field Representative, School of Civil Engineering. Study and research is usually carried on in one of the areas listed below.

* Concentration on aerial photographic studies at the Ph.D. level is offered under the subject Geotechnical Engineering.

In addition to the following formal courses, individual courses may be arranged to suit the requirements of graduate students. They are intended to be pursued under the immediate direction of the professor in charge, the student usually being free from the restriction of the classroom and working either independently or in conjunction with others taking the same course.

Courses and Research

Civil Engineering—General

2001 Thesis. The thesis gives the student an opportunity to work out a special problem or to make an engineering investigation, to record the results of his work, and to obtain academic credit for such work. Registration for the thesis must be approved by the professor in charge at the beginning of the semester during which the work is to be done.

2002 Civil Engineering Practice. Either term on demand. Credit three hours.

Analysis of large engineering works; planning and organizing engineering and construction projects; professional practice; feasibility evaluations; financial justification of projects; social and political implications. The case method will be used extensively.

2010–2011 Civil Engineering Design Project I and II. Fall term: 2010. Spring term: 2011. Credit two hours for 2010; three hours for 2011; 2010 is prerequisite to 2011. Normally required for students in the M.Eng. (Civil) program.

Design of a major civil engineering project embodying several aspects of civil engineering. Planning and part of preliminary design to be accomplished in the fall term. Remainder of preliminary design and final design in the spring term. Projects to be carried out by students working under the direction of a faculty project coordinator.

Environmental Systems Engineering

Environmental systems engineering applies systems analysis, operations research, and economics to the complex technological problems of modern society which are predominantly in the public sector. It is concerned with methods of allocation of resources in the public sector and with enhancement of the quality of information upon which to base rational decision making and public investment. Particular emphasis is placed on transportation systems; air, water, and other natural resource systems; engineering and project management; and public health, medical, and public services systems. There is special interest in the problems of urbanization, including an integrated approach to the many technological and planning aspects of modern urban areas, and to associated social and political factors.

Substantial effort is directed to the treatment of large-scale problems such as interurban and urban transportation networks, transport terminal facilities and intermodal transfer efficiency, river basin studies, disease management, optimal location of transportation links and public facilities and associated land-use patterns and land values. The economics, planning, and management of all forms of man-made and natural environment, and the associated decision-making process, are stressed. Much use is made of mathematical modeling and computers.

Master of Science and Doctor of Philosophy candidates majoring in Environmental Systems Engineering follow graduate programs comprising systems analysis, economic analysis, and a specific application area such as those described above. Applicants are considered who have undergraduate or graduate work in any area of civil engineering, in industrial engineering and operations research, and in economics. Students with other backgrounds and well-developed career objectives will also be considered for graduate studies.

In addition to the courses listed below, other courses offered throughout the University may be selected to support studies in this general subject area; see especially other offerings in Civil Engineering as well as those of City and Regional Planning, Business and Public Administration, and Economics (all in the *Announcement of the Graduate School: Social Sciences),* and Operations Research (in this *Announcement).*

301 Microeconomic Analysis. Fall term. Credit three hours. Lectures, plus discussion section. Prerequisite: one year of college-level mathematics.

Topics include the theory of the firm, production, market structures, consumer behavior, and welfare economics.

302 Macroeconomic Analysis. Spring term. Credit three hours. Lectures plus discussion. Prerequisite: 301.

Topics include the theory of international trade, national income determination, economic growth and stability, and monetary and fiscal policy.

2611 Economics of Environmental Quality Management. Either term on demand. Credit one to four hours. Prerequisite: Econ 510–511 and permission of the instructor.

A graduate seminar devoted to theoretical welfare economics and its application to the management of environmental quality.

2612 Applied Welfare Economics. Either term on demand. Credit one to four hours. Prerequisite: permission of the instructor.

This seminar is an extension of 2611 with substantially greater emphasis on the application of welfare economics, statistics, and systems analysis to public investment decisions in areas such as water resources, transportation, and public health.

2617 Environmental Systems Analysis I. Fall term. Credit one to four hours at Department's option. Prerequisite: permission of the instructor.

Structuring and solution of mathematical programming models with emphasis on linear programming and its extensions. Introduction to Lagrange multipliers, network theory, dynamic programming, nonlinear programming. Application of systems analysis techniques to the solution of complex environmental, engineering-economic problems.

2618 Environmental Systems Analysis II. Spring term. Credit three hours. Prerequisite: 2617 and Operations Research 9160 or equivalent and permission of the instructor.

Advanced topics in the application of mathematics programming and probability theory to the solution of environmental engineering problems.

2619 Location Analysis. Fall term. Credit three hours. Alternate-year course; offered 1971–72. Prerequisite: 2617 or equivalent.

Location objectives and constraints. Euclidean location. Network location. The private sector problem: plant location, heuristic and exact approaches, relation to public sector problems. The public sector problem: p-median problem, heuristic and exact approaches, the minimum-maximum time formulation. Students are required to do a project in location analysis.

2621 Theory of Traffic Flow (Operations Research 9527). Spring term. Credit three hours. Prerequisite: 9460 or permission of the instructor.

Mathematical theories of traffic flow. Including microscopic models (car following) and macroscopic models (kinematic wave theory). Stochastic properties of traffic flow at low density. Probability models for optimal control of signalized intersections. Traffic flow in transportation networks and application to traffic assignment. Traffic networks simulation system.

2622 Transportation Systems Analysis. Spring term. Credit three hours. Prerequisite: 2617, 2623 and Operations Research 9160 or equivalent.

Techniques of systems analysis are applied to physical planning, operating, and financing of transportation facilities and operations. Wherever applicable, mathematical models of transportation processes are used to examine questions related to the development of optimal policy decisions in the area of transportation. Attention is given to analysis of single and multimodal forms of transportation. Methods of mathematical programming, simulation, and stochastic processes are employed.

2623 Urban Transportation Planning. Fall term. Credit three hours. Prerequisite: 2601 or permission of the instructor.

The urban transportation problem. The urban transportation planning process, demand analysis, transportation planning models. Interaction of urban and regional transportation systems. Present and future transport modes. Predictability of demand for new modes. Analysis of economic and social impact.

2628 Airport Planning and Operations. Spring term. Credit three hours. Prerequisite: 2623.

Terminal access, location and site selection, terminal design and operations, metropolitan air transit systems, environmental impact of airport location, air traffic flow analysis, air traffic control, aircraft technology.

2632 Construction Systems Analysis. Spring term. Credit three hours. One three-hour meeting per week. Prerequisite: 2617 or consent of the instructor.

A project-oriented seminar on the identification of important construction problems and the application to them of systems analysis, designed to give the student a deep experience in the formulation, conceptualization, and mathematical modeling of construction systems as a basis for rational decision making. Normally, a single problem to be attacked is agreed upon by students and instructors. Typical problems have been (1) earth-moving and equipment scheduling on a major stretch of Interstate Highway 81, and (2) inventory control of construction projects.

2680 Environmental Control Workshop. Spring term. Credit one to three hours by arrangement with instructor.

Students interested in research topics dealing with control of the environment, with special emphasis on biological and ecological aspects, are encouraged to participate in this workshop. Topics discussed in previous workshops include human population control, control of pest and parasite populations, study of species' strategic use of food supply, control of populations by use of predators, host-parasite systems. Additional topics will be developed.

2691 Environmental Systems Design Project. Either term on demand. Credit variable. May extend over two semesters. Prerequisite: permission of the instructor.

Design of a feasibility study of environmental systems, supervised and assisted by one or more faculty advisers. Individual or group participation. Final report required.

2692 Environmental Systems Engineering Research. Either term on demand. Credit variable. Prerequisite: permission of the instructor; preparation must be suitable to the investigation to be undertaken.

Investigation in depth of particular environmental systems problems.

2693 Environmental Systems Engineering Colloquium. Fall or spring term. Credit one or two hours. Required of all graduate students with a major or minor in environmental systems engineering.

Preparation, presentation, and informal discussion of topics concerned with environmental systems. Distinguished visiting lecturers.

2694–2695 Special Topics in Environmental Systems Engineering. Credit variable. Either term on demand.

Supervised study by individuals or small groups in one or more specialized topics not covered in regular courses.

Geotechnical Engineering

Geotechnical engineering is concerned with the study of the engineering properties and use of earth materials and with the measurement of the earth and its component parts. It includes soil and rock mechanics, foundation engineering, subgrades and pavements, studies of aerial photographs and other remote sensors, physical environment evaluation, surveying, geodesy and photogrammetry.

Graduate programs are designed to provide a sound theoretical and practical background in the various branches of the subject. The research interests of the faculty members cover a wide range of problems, and modern laboratory facilities are available to students for both teaching and research.

In soil mechanics and foundation engineering, current research is related to basic strength and deformation properties of soils that are under very low effective stresses. The mechanism of the development of landslides in stiff clays as well as in very soft underwater sediments is being studied. Particular attention is being given to the relationship between soil properties and topography. In geodesy, surveying, and photogrammetry, research emphasis is on the development of photogrammetric methods for measuring the shape of large surfaces, such as that of the Arecibo Radio Astronomy Telescope, as well as of small surfaces, such as that of the human eyeball. The development of methodology for the measurement of earth movements is also being studied. Research is continuing in analytic aerotriangulation.

The work on aerial photographs and other remote sensing devices is concerned with inventory and evaluation of physical environment related to engineering, conservation, agriculture, geology, and regional planning. A large library of photographs from all over the world is available for study and research.

SOIL MECHANICS AND FOUNDATION ENGINEERING, SUBGRADES AND PAVEMENTS

2406 Foundation Engineering. Spring term. Credit three hours. Three lectures. Prerequisite: 2401.

Principles of bearing capacity and deformation theory; stress distribution; shallow and deep foundations; prediction of settlement; design of footing, raft, caisson, and pile foundations. Problems of construction, support of excavations; groundwater lowering. Foundation investigations.

2410 Engineering Properties of Soils. Fall term. Credit three hours. Three lectures. Prerequisite: 2401.

The natural environments in which soils are formed; the chemical and physical nature of soils; soil classification; the principle of effective stress; shear strength and compressibility of saturated and partly saturated soils; sensitivity; effects of anisotrophic consolidation; permeability; laboratory and field tests.

2412 Graduate Soil Mechanics Laboratory. Spring term. Credit three hours. Prerequisite: 2410.

The laboratory measurement of soil properties: classification tests; direct shear tests; triaxial tests for the measurement of pore water pressure; strength parameters. Pore pressure dissipation tests. Relationship of laboratory tests to field behavior.

2414 Earth Pressure and Seepage. Fall term. Credit three hours. Three lectures. Prerequisite: 2401.

The mechanics of the development of earth pressure in relation to soil properties and the imposed deformation conditions. The effects of seepage on the development of earth pressure. Design and stability of bulkheads and cofferdams. Pressures on shafts, tunnels, and conduits. Steady and transient flow of fluids through compressible and incompressible porous media. Consolidation processes. Sand drains. Field determination of permeability. Flow nets and modification of flow patterns by drains and relief wells.

2416 Slope Stability, Earth and Rock-Fill Dams. Spring term. Credit three hours. Three lectures. Prerequisite: 2401.

Principles of stability for earth and rock slopes; effects of pore water pressure; short-and long-term stability; problems of drawdown; analysis of landslides and dam stability; principles of earth and rock-fill dam design; internal pore water pressures and drainage; filters; relief wells; foundation problems; grouting; cutoffs; control and instrumentation.

2418 Case Studies in Soil Mechanics and Foundation Engineering. Spring term. Credit three hours.

The study of real engineering problems of various types; the importance of the geological environment in recognizing the nature of field problems; the application of mechanics and soil properties to obtain engineering solutions. The preparation of engineering reports.

2431 Pavement Design and Construction. Offered upon sufficient demand, usually in spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 2401 or permission of the instructor.

Part I: subgrade evaluation; compaction; drainage and frost action; stabilization. Part II: aggregates; bituminous materials; evaluation of flexible pavement components; design and construction of flexible pavement structure. Part III: design and construction of rigid pavements.

2432 Highway Engineering (Agricultural Engineering 491). Offered upon sufficient demand, usually in fall term. Credit three hours. Prerequisite: consent of the instructor. Principally directed study and individual or team investigations, with one 2½-hour class session per week.

Emphasis is on secondary roads in the study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

AERIAL PHOTOGRAPHIC STUDIES AND PHYSICAL ENVIRONMENT EVALUATION

2421 Physical Environment Evaluation. Fall term. Credit three hours. Two lectures, one laboratory. Permission of the instructor required.

A study of physical environment factors affecting engineering and planning decisions and the evaluation methods of these factors. Physical factors include the climate, soil and rock conditions, and water resources in different parts of the world. Evaluation methods include field reconnaissance, interpretation of meteorological, topographic, geological, and soil maps, aerial photography, engineering data, and subsurface exploration records.

2422 Advanced Physical Environment Evaluation. Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 2421, or 2423, or permission of the instructor.

A study of physical environment by use of airphotos and other remote-sensing methods. Conventional photography, sequential photography, multiple spectral photography, space photography, infrared thermal and radar imageries are included in the study. Evaluation of environment is directed to the planning of engineering and development projects in general, with some emphasis on those related to special climatic regions such as tropical humid and arid regions.

2423 Analyses and Interpretation of Aerial Photographs. Fall and spring terms. Credit three hours. Two lectures, one laboratory. (The student is expected to pay the cost of field trips and aerial photographs for use in a term project, amounting to approximately $15.)

Course presents methods of identification of a broad spectrum of soils, rocks, and drainage conditions as well as the significance of vegetative and cultural patterns of the world. Natural resources inventories and specific fields of application are emphasized.

2424 Advanced Interpretation of Aerial Photographs. Fall and spring terms. Credit three hours. Preregistration required.

Course includes lectures and team projects in laboratory and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water, and civil engineering projects.

2445 Field Practice in Geotechnical Engineering. Throughout the year. Credit one hour per semester. Field studies conducted as two-day trips on appropriate weekends in each term. (The student is expected to pay transportation and related costs, amounting to approximately $85.) Prerequisite: 2401 or permission of instructor.

This course is designed to provide experience with field conditions in important project environments within reach of the campus, including construction scenes in New York and central Pennsylvania. Preparation for and reports on various sites are a requirement. Engineering construction practices and site evaluation related to landslides, bedrock, drainage, and unstable soils. The influence of rock types, groundwater, and soil materials on existing structures; appropriate design procedures at difficult sites.

Geodetic and Photogrammetric Engineering

2452 Elements of Surveying. Fall term. Credit two hours. One lecture, one laboratory.

Fundamentals of engineering measurements. Study of observations and errors. Principles of recording data. Use of steel tape, level, and transit. Photogrammetry. Problems of particular interest to students in fields other than civil engineering.

2461 Elementary Geodesy. Fall term. Credit three hours. Three lectures.

Principal problems of geodesy. Coordinate systems, reference datum. Geometric problems on earth ellipsoid. Application of Bjerhammar singular matrix calculus; singular matrices to geodesy.

2462 Geophysical Geodesy. Spring term. Credit three hours. Three lectures.

Basic potential theory, Laplace and Poisson equations; gravity and potential field in, on, and outside the spheroid; figure of the earth, application of Stokes formula for determining undulations of the geoid and deflection of the vertical; applications of spherical harmonics.

2463 Geodetic Control Surveys. Either term on demand. Credit three hours. Two lectures, one laboratory. Prerequisite: 2451 or 2461.

Principles of establishing a geodetic sea-level datum; isostasy, the geoid and ellipsoid; altimetry, trigonometric, spirit, and electronic leveling; orthometric and dynamic heights; electronic distance measurement; triangulation and trilateration; design of control networks and systems; astronomic and gravimetric observations, and satellite triangulation.

2464 Geodetic Astronomy. Either term on demand. Credit two hours. Two lectures. Prerequisites: 2451, 2453, or equivalent work in field astronomy.

Study of the precise determination of latitude, longitude, and azimuth from astronomical observations. Night observation periods.

2465 Errors and Adjustments of Surveys. Fall term. Credit three hours. Prerequisite: laboratory work involving physical measurements. Math 293 or permission of the instructor.

Measurement systems; analysis of errors and of error propagation; application of the principles of probability to the results of measurements for the purpose of determining the best estimates of measured and deduced quantities, and the best estimate of uncertainty in these quantities; adjustment of conditioned measurements by the method of least squares and other methods; and curve fitting.

2466 Map Projections and Cartography. On demand. Credit three hours. Three lectures.

Theory of map projections including conformal, equal-area, azimuthal equidistant, et al., projections; coordinate transformations; plane coordinate systems for surveying. Design of map projections. Cartographic principles, systems, and related economic factors.

2471 Elements of Photogrammetry. Fall term. Credit three hours. Two lectures, one laboratory.

Principles and practice of terrestrial and aerial photogrammetry including: flight planning, control requirements, geometry of a photograph, simple stereoplotting instruments, parallax distortions, mosaics and orthophotos, semigraphical and analytical tilt determinations. Charting from space photography. A three-projector Balplex double-projection stereoplotter is used for basic mapping instruction.

2472 Advanced Photogrammetry. Either term on demand. Credit three hours. Two lectures, one laboratory. Prerequisite: 2471.

An advanced study of photogrammetric principles including: rectification; graphical and instrumental aerotriangulation; mapping from space photography; geometry of remote sensors. A first-order Wild A-9 Autograph is used for aerial mapping instruction. A Zeiss Stereometric Camera and Terragraph Plotter are used for terrestrial mapping and for non-topographic, metric, and documentation problems.

2473 Analytical Aerotriangulation. Either term on demand. Credit three hours. Three lectures. Prerequisite: 2471.

Analysis, theories, and computation of stereostrip triangulation by direction cosines, vector, and matrix methods. Coplanarity and colinearity equations for relative orientation and absolute orientation. Stereogram assemblage and coordinate transformation of strip and block coordinates. Cantilever extension and general bridging solutions. Propagation of errors.

2481 Cadastral Surveying. On demand. Credit three hours. Three lectures.

Study of legal principles and surveying operations associated with acquisition of evidence for the delineation of boundaries of real estate. Topics covered include: metes and bounds, subdivision, and other methods of description of real property; land courts; riparian rights; mineral rights; resurveys; and authority and responsibilities of the cadastral surveyor.

2482 Engineering Surveys. Spring term. Credit three hours. One lecture, two laboratories. Prerequisite: 2451 or equivalent.

Circular curves, transition curves, earthwork measurement and calculation, topographic surveys, construction surveys, and project planning from maps.

2491 General Design Project in Geotechnical Engineering. Either term. Credit one to six hours.

Design problems frequently associated with the M.Eng. program.

2492 Research in Geotechnical Engineering. Either term on demand. Credit one to six hours.

For students who wish to study one particular area of geotechnical engineering in depth. The work may take the form of a laboratory investigation, field study, theoretical analyses or the development of design procedures.

2493 Seminar in Geotechnical Engineering. Fall and spring terms. Credit one to two hours.

Presentation and discussion of technical papers and current research in the general field of geotechnical engineering or one of its specialized fields.

2494 Special Topics in Geotechnical Engineering. Either term on demand. Credit one to six hours.

Supervised study in small groups in one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

2495 Seminar in Geodetic and Photogrammetric Engineering. Fall and spring terms. Credit one hour.

Student presentation, discussion, and editing of technical papers and review of current research in geodesy, photogrammetry, cartography, and land surveying. Occasional guest speakers.

Hydraulics and Hydrology

Two modern laboratories make possible a wide range of instructional and research experimentation. In the applied fluid mechanics laboratory in Hollister Hall, well-instrumented models support experimental studies in all phases of fluid flow. At the Applied Hydraulics Laboratory near Beebe Lake, flows up to fifty cubic feet per second and natural heads up to eighty feet are available for both research and testing.

Current staff research in hydraulics and hydrology includes studies in lake circulation; mathematical models of hydrologic systems; nonlinear storage routing methods; drainage from large unconfined aquifers; recovery of infiltration capacity in soils with hysteresis; permeability models for porous materials; time series analysis of lake evaporation; random structure of drought flows; physics of lake evaporation; heat transfer from lakes.

2303 Hydrology. Fall term. Credit three hours. Three lecture-recitations. Prerequisite: 2301.

Introduction to hydrology including topics on precipitation, evapo-transpiration, groundwater, surface water, sedimentation.

2312 Experimental and Numerical Methods in Fuid Mechanics. Fall and spring terms. Credit two hours. Prerequisite: 2302 or permission of the instructor. Primarily a laboratory course; may be repeated for credit with permission of the instructor.

Emphasis is on planning and conducting laboratory and field experiments and on numerical computation.

2315 Advanced Fluid Mechanics I. Fall term. Credit three hours. Three recitations. Prerequisite: 2301.

Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy. Similitude and modeling potential flow including circulation, vorticity, conformal mapping, and hodograph methods.

2316 Advanced Fluid Mechanics II. Spring term. Credit three hours. Three recitations. Prerequisite: 2315.

Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics.

2317 Free Surface Flow. Spring term. Credit three hours. Three recitations. Prerequisite: 2315 or permission of the instructor.

The formulation of the free surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels. Theory of small-amplitude waves.

2318 Dynamic Oceanography. Fall term. Credit three hours. Prerequisite: elementary fluid mechanics.

The statics and dynamics of oceans and lakes. Currents in homogeneous and stratified bodies of water. Tides, seiches, waves, and tsunamis. Turbulence and diffusion.

2320 Surface Water Hydrology. Fall term. Credit three hours. Prerequisite: 2301.

Physical and statistical analysis relating to hydrologic processes. Hydrometeorology and evaporation. Surface runoff, base flow and storage routing in linear and nonlinear systems. Unit hydrograph theory.

2321 Flow in Porous Media. Spring term. Credit three hours. Prerequisite: 2301 (also recommended, 2315).

Fluid mechanics of flow through porous solids. The general equations of single-phase and multiphase flow and the methods of solving the differential form of these equations. Hydraulics of wells, of infiltration and of groundwater recharge, and of other steady-state and transient seepage problems in fully and partially saturated materials.

2391 Project. Either term on demand. Hours and credit variable.

The student may elect a design problem or undertake the design and construction of special equipment in the fields of fluid mechanics, hydraulic engineering or hydrology.

2392 Research in Hydraulics. Either term on demand. Hours and credit variable.

The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either of an experimental or theoretical nature. Results should be submitted to the instructor in charge in the form of a research report.

2393 Hydraulics Seminar. Spring term. Credit one hour. Required of graduate students majoring in hydraulics or hydraulic engineering.

Current topics in fluid mechanics, hydraulic engineering, and hydrology.

2394 Special Topics in Hydraulics. Either term on demand. Hours and credit variable.

Special topics in fluid mechanics, hydraulic engineering, or hydrology.

Sanitary (Environmental) Engineering and Water Resource Systems Engineering

Environmental quality (sanitary) engineering is concerned with planning and controlling the quality of the air-land-water environment for the benefit of society. Graduate study in this subject enables the student to gain a fundamental knowledge of the pertinent biological, chemical, physical, and engineering phenomena and principles, as well as developing analytical, computational, and laboratory skills. The degree programs emphasize the application of these phenomena, principles, and skills to the analysis and design of processes, facilities, systems, and policies for environmental quality control and waste management. Advanced study in environmental resource systems offers an opportunity to develop and combine competence in environmental quality control technology, economic theory, and operations research; and to apply this knowledge to the solution of engineering problems in water resource planning and management and in environmental quality control. The sanitary engineering facilities contain approximately 6,300 square feet of laboratory space and controlled-temperature rooms and include separate specially equipped laboratories for water bacteriology and biology, water chemistry, bench and pilot-level unit process studies, and radiological measurements.

Students and staff are currently collaborating in such diverse research areas as the kinetics and the control of biological waste treatment processes; nitrification and denitrification reactions in waste waters and in receiving waters; physico-chemical treatment of waste water; solid wastes management; treatment and disposal of industrial wastes; mathematical decision models for water quality control; optimization of water and waste treatment process design and plant operation; mathematical decision models for the operation of water resource systems; water pollution control policies; and noise control.

2502 Environmental Quality Analysis and Evaluation. Fall term. Credit three hours. One lecture, two laboratory or computations. Prerequisite: 2301 or equivalent, 2501.

Examination, analysis and evaluation of specific environmental quality problems. Theoretical and experimental investigation of specific environmental quality control processes and facilities. Emphasis on waste control technology, and waste assimilation in water.

2503 Water Quality Engineering. Spring term. Credit three hours. Two lectures, one laboratory or computation. Prerequisites: 2301, 2502 or equivalent or permission of instructor.

Introduction to water quality engineering, including water supply, water and waste water treatment and disposal. Principles applicable to the behavior of municipal and industrial effluents in natural waters. Elements of analysis and design of municipal water supply systems and waste water and storm water collection and disposal systems.

2510 Chemistry of Water and Waste Water. Fall term. Credit three hours. Three lectures. Prerequisite: one year of college chemistry.

Principles of physical, organic, inorganic, and biochemistry applicable to the understanding, design, and control of water and waste water treatment processes, and to reactions in receiving waters.

2513 Biological Phenomena and Processes. Fall term. Credit four hours. Three lectures, one laboratory. Prerequisite: 2503 or equivalent and concurrent registration in 2510.

Theoretical and engineering aspects of biological phenomena and processes applicable to the removal of impurities from water, waste water, and industrial wastes, and to their stabilization in receiving waters. Pertinent microbiological principles, biological oxidation, kinetics, and eutrophication. Analysis and design of biological treatment processes. Laboratory studies of pertinent phenomena and processes.

2514 Chemical and Physical Phenomena and Processes. Spring term. Credit four hours. Three lectures, one laboratory. Prerequisite: 2503 or equivalent and 2510.

Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, waste water, industrial wastes, and receiving waters; reaction kinetics, transfer and dispersion phenomena, and fine particle mechanics. Analysis and design of conventional and advanced treatment and disposal processes. Laboratory studies of pertinent phenomena and processes.

2515 Water Resources Problems and Policies. Fall term. Credit three hours. Lecture-discussion. Prerequisite: permission of the instructor.

A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water resources problems, organization, and policies.

2518 Water Resource Systems. Spring term. Credit three hours. Prerequisite: 301 and 2617 or Operations Research 9522, or permission of the instructor.

Application of economics, engineering, and systems theory to water, waste water and related resource planning and management problems. Development of deterministic and stochastic models. Review of current literature.

2520 Environmental Health Engineering. Spring term. Credit three hours. Three lecture-discussions. Prerequisite: permission of the instructor; intended primarily for graduate students in engineering.

Environmental quality concepts and objectives. Pertinent principles of ecology, epidemiology, toxicology, and radiological health. Environmental quality control methods, including air quality control, water quality control, solid waste disposal; economic, legal and technological aspects.

2530 Solid Waste Management. Spring term. Credit three hours. Lecture, reports. Prerequisite: permission of the instructor.

Study of municipal, industrial, and agricultural solid waste. Emphasis on waste characteristics, methods of treatment and disposal, and interrelationships with the air, water, and land environment.

2531 Industrial Waste Management. Spring term in alternate years. Credit three hours.

Legal aspects, assimilatory capacity of receiving waters, waste sampling and analysis, treatment processes, waste reduction possibilities, waste quantity and quality, reuse and recovery, joint industry-municipal treatment of waters, sewerage service charges, case studies.

2533 Environmental Quality Control. Fall term; spring term on demand. Credit three hours. Three lecture-discussions, field trips. Prerequisite: permission of the instructor.

Introduction to environmental quality problems, their relation to man's activities, and their management; the ecological, economic, and technological aspects of air quality control, water quality control, and the control of liquid, solid and gaseous wastes.

2534 Air Quality Control. Spring term. Credit three hours. Three lecture-discussions. Prerequisite: permission of instructor.

Elements of air quality control. Sources, nature, and dispersion of gases and particles in the atmosphere. Air quality effects, objectives and standards. Air quality control technology.

2545 Water Resources Planning Seminar. Spring term. Credit three hours. Prerequisite: 2515 or permission of the instructor.

The concepts, processes, and techniques of regional, multipurpose river basin planning and development. The case study method, with preparation of an integrated, comprehensive report for the study area, is used.

2547 Environmental Policy Analysis. Fall term. Credit three hours. Prerequisite: 301, 2518 or 2618, Operations Research 9360, or permission of the instructor.

Current research topics in the application of economic optimization and simulation techniques for defining and evaluating public policy alternatives for managing air, land, and water resources and the material and energy wastes released into the environment. The influence of technologic, economic, and political uncertainty will be emphasized. Each student will select a particular environmental management problem and structure models or methods for analyzing alternative solutions.

2591 Design Project. Either term on demand. Credit variable. Prerequisite: 2503 or equivalent.

The student will elect or be assigned problems in the design of water and waste-water treatment processes or plants; waste-water disposal systems; water quality control systems; water resource development or management systems; or laboratory apparatus of special interest.

2592 Sanitary Engineering Research. Either term on demand. Credit variable. Prerequisites will depend upon the particular investigation to be undertaken.

For the student who wishes to study a special topic or problem in greater depth than is possible in formal courses.

2593 Water Resources Engineering Colloquium. Fall and spring terms. Credit one or two hours.

Presentation and discussion of current topics and problems in sanitary engineering and water resources engineering. Required of graduate students majoring or minoring in either subject.

2594 Special Topics in Sanitary and Water Resource Systems Engineering. Either term on demand. Hours and credit variable.

Supervised study in special topics not covered in formal courses.

Structural Engineering

Structural engineering embraces not only the more conventional aspects of civil engineering design but also other structural work, such as aeronautical and space structures, nuclear engineering structures, tanks, bins, pressure vessels, antenna towers, and the like. Emphasis is placed on the common fundamental background, theoretical and experimental, of all structural engineering. Structural and materials behavior being inseparably related, instruction and research in the field of structural materials is regarded as part of the area of structural engineering.

Complete facilities for experimental structural research of all kinds are available, including a structural testing hall fifty feet by eighty feet in plan, and forty-five feet high for full-scale three-dimensional static and fatigue testing of structures; static- and fatigue-testing machines of a variety of capacities; appropriate measuring equipment; a versatile and fully equipped structural models laboratory; and a large laboratory for concrete and other cementitious materials.

The facilities of the University computing center, including the IBM 360–65, are available for use by graduate students in course work and research.

The Department has a large number of externally and internally sponsored research projects upon which students can base theses and receive research assistantships. The externally sponsored projects include: shell structures of light gage steel, microcracking of concrete and its influence on structural behavior and fracture, behavior of beams and columns braced by diaphragms, analysis methods for light gage steel floor diaphragms, performance of stainless steel structural members, torsional-flexural buckling of eccentrically loaded columns, fundamental concepts of cracking phenomena in reinforced concrete structures, biaxial stress-strain properties and strength of concrete, bond stress-slip relations in reinforced concrete, effects of cold forming on performance of light gage steel members, influence of ductility on structural behavior, cable-suspended roof structures, anchorage systems in prestressed concrete reactor vessels, reinforced concrete models, and structural reliability.

A brochure on *Structural Engineering at Cornell University* is available on request from the School of Civil Engineering, Hollister Hall.

2702 Structural Engineering II. Spring term. Credit three hours. Two lectures, one two-hour period. Prerequisite: 2701 and coregistration in 2751. Evening examinations.

Deflections and analysis of indeterminate structures by method of virtual work. Cable structures and prestressing concepts. Properties and behavior of reinforced concrete. Behavior under load of reinforced concrete beams, columns, and beam columns.

2703 Structural Engineering III. Fall term. Credit three hours. Two lectures, one two-hour period. Prerequisite: 2702, 2751.

Continuation of indeterminate analysis topics of 2702, including Castigliano's theorems, moment distribution, and matrix structural analysis. Collapse theory and plastic design concepts. Structures subjected to moving loads (influence lines). Applications to steel and concrete structures.

2704 Structural Design. Spring term. Credit three or four hours. Two lectures, one or two two-hour periods. Prerequisite: 2703.

Comprehensive design project drawing on material from previous courses in structures and materials. Additional design topics such as approximate analysis and preliminary design, choice of structural form, shell structures, timber structures, structural models, connections, composite construction.

2710 Strength of Structures. Fall term. Credit three hours. Three recitations. Prerequisite: 2703; can be taken concurrently.

Analysis of two- and three-dimensional stress and strain. Theories of failure of ductile and brittle materials. Microstructure of materials. Structural materials under load, strain hardening, Bauschinger effect, residual stresses, hysteresis, stress concentration, brittle fracture, creep, alternating stress. Design for fatigue. Stresses beyond the elastic limit. Inelastic behavior of steel and reinforced concrete structures. Critical discussion of recent research and current design specifications.

2711 Buckling: Elastic and Inelastic. Spring term. Credit three hours. Prerequisite: 2710.

Analysis of elastic and plastic stability.

Determination of buckling loads and post-buckling behavior of columns. Solid and open-web columns with variable cross-section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral strength of unbraced beams. Buckling loads and post-buckling behavior of plates, shear webs, and cylindrical shells. Critical discussion of current design specification.

2712 Advanced Structural Analysis. Fall term. Credit three hours. Three lectures. Prerequisite: 2703; concurrent registration in CS 311.

Stability, determinacy, redundancy of structures. Approximate methods of analysis. Force, displacement, and transfer matrix methods of matrix structural analysis. Development of space frame element equations, including distributed loads and thermal strain effects. Methods of solution: direct and iterative, tridiagonalization, partitioning, and special transformations. Analysis techniques for tall buildings and other special problems.

2713 Finite Element Analysis. Spring term. Credit three hours. Three lectures. Prerequisite: 2712.

Theoretical and conceptual bases for formulation of finite element representations in continuum mechanics. Development of element relationships for structural analysis of plates, shells, and solids. Extension of element and system solution techniques to deal with problems in elastic stability, inelastic deformation, finite displacements, dynamic response, and other special behavior mechanisms.

2714 Structural Model Analysis and Experimental Methods. Fall term. Credit three hours. Two lectures, one two-hour period. Prerequisite: indeterminate analysis.

Dimensional analysis and principles of similitude. Direct model analysis, including materials, fabrication, loading, and instrumentation techniques. Basic techniques of experimental stress analysis. Confidence levels for model results. Laboratory projects in elastic behavior and ultimate strength of model structures.

2715 Numerical Methods and Probability. Spring term. Credit three hours. Prerequisite: differential equations and consent of the instructor; concurrent registration in CS 311.

Numerical integration techniques. Solution of linear and nonlinear systems. Finite difference techniques for boundary value problems. Computer applications. Introduction to probability concepts pertaining to structural analysis and design. Structural reliability; inference techniques; decision theory; stochastic processes.

2716 Concrete Structures I. Fall term. Credit three hours. Three lectures. Prerequisite: 2703, can be taken concurrently.

Analysis, design, and behavior of prestressed concrete structures; beams, slabs, composite construction, continuous beams and frames, tension and compression members; deflection analysis, end zone stresses, detailing losses, efficiency. Design of concrete shells; shells of revolution, hyperbolic paraboloids.

2717 Concrete Structures II. Spring term. Credit three hours. Three lectures. Prerequisite: 2703.

Analysis, design, and behavior of reinforced concrete structures; safety considerations, deflection analysis, crack control; beams, columns, slabs, continuous frames, flat plates, flat slabs, composite construction; limit analysis and yield line theory; design of concrete shells; folded plates and cylindrical shells.

2718–2719 Behavior and Design of Metal Structures. Fall and spring terms. Credit three hours each term. Prerequisite: 2703; can be taken concurrently.

Contemporary methods for analyzing and designing metal structures. Behavior of structural elements and frames. Selected design applications from the fields of steel plate structures, bridges, suspension systems, lightweight structures.

2720 Shell Theory and Design. Fall term. Credit three hours. Prerequisite: Math 294 or equivalent and consent of the instructor.

Differential geometry of surfaces. Bending and membrane theory of shells. Analysis and design of cylindrical shells, domes, paraboloids. Application to reinforced concrete roofs and pressure vessels. Stability of certain types of shells.

2722 Dynamics of Structures. Spring term. Credit three hours. Prerequisite: Math 294 or equivalent and consent of the instructor.

Equations of motion and vibration of simple systems. Numerical, energy, and matrix methods of analysis of multiple-degree systems. Analysis and design of structures for ground disturbances, including inelastic effects.

2730 Aerospace Structural Analysis I. Fall term. Credit three hours. Prerequisite: Mechanics 211 and 212.

Evolution of aerospace structural design concepts and the structural design cycle. Environment, structural design criteria and specifications for aircraft, missiles, and spacecraft. Inertia loads, load factors, flight envelopes, gust loads. Aerodynamic and solar heating, loads in space flight. Materials of construction and their properties; elastic and inelastic behavior, fatigue. Theories of failure. Fracture mechanics. Elementary structural analysis.

2731 Aerospace Structural Analysis II. Spring term. Credit three hours. Prerequisite: Mechanics 211 and 212.

Structural problems and configurations of aircraft, missiles, and spacecraft. Analysis and design of thin-walled members in bending, torsion, and combined loadings. Reinforced stressed skin construction, thick shell construction, sandwich and composite materials. Inelastic analyses: plastics and viscoelastic behavior. Buckling, torsional instability and crippling of thin-walled beams; creep buckling. Buckling and postbuckling behavior of plates; effective width. Thermal stresses and high-temperature effects.

2732 Optimum Structural Design. Fall term. Credit two hours. Prerequisite: 2617 or equivalent and consent of the instructor.

Classification of optimum structural design problems; merit functions and design variables. Fully stressed design. Mathematical programming methods in optimum structural design, including linear programming, gradient projection, and penalty function procedure. Classical methods, including Lagrangian multipliers and variational concepts. Application to truss and beam design situations is emphasized.

2751 Engineering Materials. Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 6210.

Engineering properties of concrete; engineering properties of steel, wood, and other selected structural materials; physico-chemical properties of soils, concrete, and bituminous materials. Design characteristics and significance of test results of materials used in engineering works. Extensive laboratory testing and report writing.

2752 Advanced Plain Concrete. Fall term. Credit three hours. Two lectures plus conference. Prerequisite: 2751 or equivalent.

Topics in the field of concrete, such as history of cementing materials, air-entrainment, lightweight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relationships between internal structure, physical properties, chemical properties, and the mechanical properties of interest to the design and construction engineer.

2753 Structure and Properties of Materials. Spring term. Credit three hours. Two lectures plus conference. Open to graduate students in the physical sciences.

Internal structure of materials ranging from the amorphous to the crystalline state. Forces holding matter together versus forces causing deformation and failure. Correlation of the internal structures of materials with their physical and mechanical properties. Applications to various engineering materials.

2757 Civil Engineering Materials Project. Either term on demand. Credit one to six hours.

Individual projects involving civil engineering materials.

2758 Civil Engineering Materials Research. Either term on demand. Hours and credit variable.

Individual assignments, investigations and/or experiments with civil engineering materials.

2791 Design Project in Structural Engineering. Fall and spring terms. Credit one hour fall term, three hours spring term; both terms required. Meets project requirement for M.Eng. degree.

Comprehensive design projects by design teams. Formulation of alternate design proposals, including economics and planning, for a given situation and complete design of the best alternate. Determination of construction costs and preparation of sketches and drawings. Presentation of designs by oral and written reports.

2792 Research in Structural Engineering. Either term on demand. Hours and credit variable. For students wishing to pursue one particular branch of structural engineering beyond the scope of the regular courses; prerequisite courses depend upon the nature of the work desired.

The work may be in the nature of an investigation of existing types of construction, theoretical work with a view toward simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

2793 Structural Engineering Seminar. Spring term. Credit one to three hours.

Preparation and presentation of topics of current interest in the field of structures for informal discussion.

2794 Special Topics in Structural Engineering. On demand. Hours and credit variable.

Individually supervised study in one or more of the specialized topics of civil engineering, such as tanks and bins, suspension bridges, towers or movable bridges, which are not covered in the regular courses. Independent design or research projects may also be selected.

Computer Science

Faculty
H. D. Block, James H. Bramble, Kenneth M. Brown, Robert L. Constable, Richard W. Conway, John E. Dennis, David Gries, Juris Hartmanis, John E. Hopcroft, Ellis Horowitz, William L. Maxwell, Charles W. Merriam, Jorge Moré, Howard L. Morgan, Anil Nerode, Christopher Pottle, Gerard Salton, Alan C. Shaw, Robert A. Wagner, Robert J. Walker, John H. Williams

Field Representative
David Gries, Upson Hall

MAJOR AND MINOR SUBJECTS
Computer Science
Information Processing
Numerical Analysis
Theory of Computation

ADMISSION REQUIREMENTS. Applicants are expected to have had significant experience in programming a digital computer and, depending upon the particular subject major chosen, appropriate background in mathematics, engineering, linguistics, etc., to permit immediate enrollment in graduate-level courses. A student is also expected to have had at least an introductory course in computer science, although this deficiency can be remedied after admission.

LANGUAGE REQUIREMENTS. A candidate for the degree of Ph.D. must demonstrate reading ability in one approved language besides English. Approved languages are French, German, Russian, and any language in which there exists a substantial body of literature in the area of the student's doctoral thesis. The Field requires no foreign language for the M.S. degree. Any Special Committee may, at its discretion, impose additional language requirements.

OTHER FIELD REQUIREMENTS. All candidates for the Ph.D. are required to have at least one minor in a field other than computer science. The most frequent choices are the Fields of Mathematics, Applied Mathematics, Statistics, Operations Research, Electrical Engineering, Ecology and Evolutionary Biology, Psychology, or Linguistics, but others would be possible. One semester of part-time teaching experience is also required for the Ph.D. degree.

Examinations required by the Graduate School are described on p. 11 of this *Announcement.*

AIMS AND OPERATIONS OF THE FIELD. The Field of Computer Science at Cornell is concerned with fundamental knowledge in automata, computability, and programming languages and systems programming, as well as with subjects such as numerical analysis and information processing, which underlie broad areas of computer applications. Because of the wide implications of research in the field, the Department of Computer Science is organized as an intercollege department in the College of Arts and Sciences and the College of Engineering.

A graduate student should consider a major in computer science if he is primarily interested in the general aspects of computational processes, both theoretical and practical, e.g., theory of algorithms, methods by which algorithms are implemented on a computer, and information structures. If he is primarily interested in the results of a computer process and its relation to a particular area of application, then he should major in another field and consider a minor in computer science.

RESEARCH AND STUDY OPPORTUNITIES. Opportunities exist for research and study in the following areas: numerical analysis (Bramble, Brown, Dennis, Moré, Walker), programming languages and systems (Conway, Gries, Maxwell, Morgan, Shaw, Wagner, Williams), automata and computability theory (Constable, Hartmanis, Hopcroft, Nerode), information organization and retrieval (Salton), systems and control theory (Merriam, Pottle), adaptive systems (Block).

COMPUTING FACILITIES. The principal computing facility at Cornell is an IBM 360 Model 65. This is located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus, and is directly linked to satellite computers at three different campus locations. The Engineering College and the Department of Computer Science are served through one of these satellite stations in Upson Hall as well as by a number of teletypewriter terminals in different locations. An IBM 1800 computer is also linked to the central computer to provide an analog-digital interface and graphical display equipment.

A booklet describing in more detail the graduate work in Computer Science and closely related subjects at Cornell can be obtained by writing to: Field Representative, Upson Hall.

Courses

385 Introduction to Automata Theory. Spring term. Credit three hours. Prerequisite: 203 or Math 222 or 294.

Models of abstract computing devices. Finite automata and regular expressions and sets. Input-output experiments, nondeterministic machines, parallel and sequential realizations, and algebraic structure theory. Pushdown automata and context-free languages. Closure properties and decision problems. Turing machines and recursively enumerable sets. Universal Turing machines, the halting problem, decidability.

401 Computer Organization and Programming. Either term. Credit four hours. Prerequisite: Math 221 or 293 or equivalent; previous programming experience helpful but not required. Lecture and laboratory.

Characteristics and structure of digital computers as hardware units. Representation of data, complement arithmetic, floating point; addressing of data, index registers, indirect and base-plus-displacement addressing. Codes for error detection and corrections. Introduction to computer microstructure, gates, flipflops, adders. System supplied programs, loaders, assemblers, interpreters, and compilers. Storage and peripheral hardware and their characteristics, the input-output channel, interrupts. Characteristics of operating systems. Although several programs, including at least one in machine language, will be assigned, this course is not primarily designed to teach programming. Rather, it is intended for students who want to know more about computers than programming. Students should be warned that in using 401 as a prerequisite to further course work in the Information Processing area, they will be somewhat deficient in assembly language programming experience.

404 Advanced Computer Programming. Spring term. Credit four hours. Prerequisite: 202, 401 or consent of the instructor.

For students who wish to learn computer programming for eventual use in professional systems programming or advanced applications. To develop this ability, the basic logical and physical structure of digital computers is considered and the applicability and limitations of the structure are studied through many examples and exercises. The approach, therefore, is not a theoretical one, but rather an engineering one, emphasizing techniques. Students participate in a large systems programming design and implementation effort.

409 Data Structures. Fall term. Credit four hours. Prerequisite: 202 or 401 or equivalent.

Data structures, relations between data elements, and operations upon data structures. Bits, bytes, fields, arrays, stacks, trees, graphs, lists, strings, records, files and other forms of data structures. Primitive operations, accessing techniques, and storage management techniques appropriate to each class of data structures. Sorting and searching techniques, symbol table structures. Data structures in programming languages, retrieval systems, and data management systems. Formal specification of classes of information structures.

411 Programming Languages. Fall term. Credit four hours. Prerequisite: 202 or 401 or consent of the instructor.

An introduction to the structure of programming languages. Specification of syntax and semantics. Properties of algorithmic, list processing, string manipulation, and simulation languages: basic data types and structures, operations on data, statement types, and program structure. Macro languages and their implementation. Run-time representation of programs and data. Storage management techniques. Introduction to compiler construction.

412 Translator Writing. Spring term. Credit four hours. Prerequisite: 411, or consent of the instructor.

Models and techniques used in the design and implementation of assemblers, interpreters, and compilers. Topics include: lexical analysis in translators, compilation of arithmetic expressions and simple statements, specification of syntax, algorithms for syntactic analysis, code generation and optimization techniques, bootstrapping methods, compiler-compiler systems.

413 Systems Programming and Operating Systems. Fall term. Credit four hours. Prerequisite: 409 or consent of the instructor.

The organization and software components of modern operating systems. Batch processing systems: loaders, input-output methods. Cooperating sequential processes: parallel programming, synchronization techniques. Introduction to multiprogrammed systems: the "process" model, virtual machines. Storage management: relocation, protection, allocation. Procedure and data sharing. Process scheduling and control. General resource management. File systems: logical and physical organization, protection. Case studies. Additional topics such as systems simulation, job control languages, and microprogramming. Projects involving design and implementation of systems modules.

415 Machine Organization. Spring term. Credit four hours. Prerequisite: 202, 401, or consent of the instructor.

Design and functional organization of digital computers. Boolean algebra, elements of logical design and computer components. Counters, shift registers, half and full adders, design of arithmetic units. Memory components, accessing and retrieval techniques, addressing structures, realization of indexing and indirect addressing. Control unit structure, instruction decoding, synchronous and asynchronous control. Input-output channels, buffering, auxiliary memory structure, interrupt structures. Overall systems organization, reliability, system diagnostics, system simulation.

416 Operations Research Models for Computer and Programming Systems. Spring term. Credit four hours. Prerequisite: 411 and a course in probability (e.g., Math 371 or Operations Research 9460), or consent of the instructor.

Modeling and analysis of computer hardware and software systems. Some applications of the theories and techniques of operations research to problems arising in computer systems design and programming. Operating systems design: resource allocation and scheduling. Queuing models for time-sharing and multiprogramming systems. Reliability of computer systems and computer networks. Statistical techniques for measuring systems performance. Simulation of hardware and software; systems balancing. Applications of stochastic processes and inventory theory, e.g., file organization and management, models of computer center operation. Mathematical programming techniques applied to hardware configuration selection. Students will program and analyze a model which can be applied to a problem of hardware or software design.

420 Computer Applications of Numerical Analysis. Fall term. Credit four hours. Prerequisite: Math 222 or 294 and Computer Science 311 or equivalent programming experience.

Modern computational algorithms for the numerical solution of a variety of applied mathematics problems are presented and students solve current representative problems by programming each of these algorithms to be run on the computer. Topics include numerical algorithms for the solution of linear systems; finding determinants, inverses, eigenvalues and eigenvectors of matrices; solution of a single polynomial or transcendental equation in one unknown; solution of systems of nonlinear equations; acceleration of convergence; Lagrangian interpolation and least squares approximation for functions given by a discrete data set; differentiation and integration; solution of ordinary differential equations; initial value problems for systems of nonlinear first order differential equations, two-point boundary value problems; partial differential equations; finite difference grid technique for the solution of the Poisson equation.

421–422 Numerical Analysis. Throughout the year. Credit four hours a term. Prerequisite: Math 412 or 416 or 422 or consent of the instructor.

A mathematical analysis of numerical methods from the areas of solution of linear systems of equations, matrix inversion, eigenvalue and eigenvector determination, nonlinear equations, polynomial approximation, interpolation, differentiation, integration, ordinary and partial differential equations. Practical experience will be gained in the laboratory.

435 Information Organization and Retrieval. Spring term. Credit four hours. Prerequisite: 401 or equivalent.

Covers all aspects of automatic language processing on digital computers, with emphasis on applications to information retrieval. Analysis of information content by statistical, syntactic and logical methods. Dictionary techniques. Automatic retrieval systems, question-answering systems. Evaluation of retrieval effectiveness.

441 Heuristic Programming. Spring term. Credit four hours. Prerequisite: 401 and 411.

485 Theory of Automata I. Fall term. Credit four hours. Prerequisite: 203 or 401 or consent of the instructor.

Automata theory is the study of abstract computing devices; their classification, structure and computational power. Topics include finite state automata, regular expressions, decomposition of finite automata and their realization, Turing machines and their computational power.

486 Theory of Automata II. Spring term. Credit four hours. Prerequisite: 485 or consent of the instructor.

Topics include context-free and context-sensitive languages and their relation to pushdown and linearly bounded automata. Quantitative aspects of Turing machine computations: time- and memory-bounded computations with applications to language processing and classification of other automata and computations. Axiomatic computational complexity theory and complexity hierarchies.

487 Formal Languages. Fall term. Credit four hours. Prerequisite: 486 or consent of the instructor.

A study of formal languages, their processing and processors. Topics include regular, context-free, and context-sensitive languages; their recognition, parsing, algebraic properties, decision problems, recognition devices, and applications to computer and natural languages.

488 Theory of Effective Computability. Spring term. Credit four hours. Prerequisite: 401, 485, Math 481 or consent of the instructor.

Turing machines and Church's thesis, universal Turing machines, unsolvability of the halting problem. Recursively enumerable sets, productive and creative sets, relative computability, the recursion theorem. Post's problem. Computational complexity hierarchies.

517 Picture Processing. Spring term. Credit four hours. Prerequisite: 411 or consent of the instructor.

A study of computer graphics and digital picture analysis. Topics include display and digitization hardware, picture data structures, preprocessing and feature detection, the receptor categorizer model of pattern recognition, linguistic methods in picture processing, mathematics of picture transformations, graphics programming languages and systems.

521 Solutions of Nonlinear Equations and Nonlinear Optimization Problems. Spring term. Credit four hours. Prerequisite: 422 or consent of the instructor.

The course will emphasize the rigorous analysis of practical numerical algorithms for nonlinear problems. Sample topics are nonlinear functional analysis, nonlinear curve fitting, computationally convenient modifications of Newton's method and descent methods, applications to control theory and integral equations, constrained optimization.

523 Numerical Solution of Ordinary Differential Equations and Integral Equations. Fall term. Credit four hours. Prerequisite: 422 or consent of the instructor.

Topics include solution of initial value problems and boundary value problems by quasi-linearization and variational techniques as well as discrete variable methods; rigorous stability analysis for standard multistep methods and modified multistep methods for stiff systems.

525 Numerical Solution of Partial Differential Equations. Spring term. Credit four hours. Prerequisite: 523 or consent of the instructor.

General classification; solution by method of characteristics; finite-difference methods for hyperbolic and elliptic equations; parabolic equations in two dimensions; direct solution of elliptic finite-difference equations; iterative methods for the solution of elliptic equations; block methods for large systems; singularities in elliptic equations; stability in relation to initial value problems and nonlinear discretization algorithms.

527 Introduction to Approximation Theory. Fall term. Credit four hours. Prerequisite: 422 or consent of the instructor.

The study of the characterization of best linear and nonlinear (L_p) approximations to real functions, the Remez algorithm, best approximations to bounded linear functionals with applications to quadrature theory and optimal approximations.

587 Computational Complexity. Fall term. Credit four hours. Prerequisite: 486 or 488 or consent of the instructor.

General measures of computational complexity and methods of classifying computable (recursive) functions. Examples of topics include restricted Turing machines, time- and memory-bounded computations as well as quantitative results about formal languages.

590 Special Investigations in Computer Science. Throughout the year. Credit to be arranged. Prerequisite: consent of the registration officer of the Department.

Offered to qualified students individually or in small groups. Directed study of special problems in the field of computer science.

591 Computer Science Graduate Seminar. Throughout the year. Credit one hour. Staff, visitors, and students.

A weekly meeting for the discussion and study of important topics in the field.

611 Seminar in Programming. Either term. Credit four hours. Prerequisite: 411 or consent of the instructor.

621 Seminar in Numerical Analysis. Either term. Credit four hours. Prerequisite: consent of the instructor.

635 Seminar in Information Organization and Retrieval. Fall term. Credit four hours. Prerequisite: 435.

681 Seminar in Automata Theory. Either term. Credit four hours. Prerequisite: 486 or consent of the instructor.

Operations Research 9580 Digital Systems Simulation. Fall term. Credit four hours. Prerequisite: 401 and Operations Research 9470 or consent of the instructor.

Operations Research 9582 Data Processing Systems. Fall term. Credit three hours. Prerequisite: 401 or consent of the instructor.

Electrical Engineering 4487–4488 Switching Theory and System. Fall and spring terms. Credit three or four hours per term. Prerequisite: Math 293–294 or equivalent; first term prerequisite to second.

Electrical Engineering

Faculty
Paul D. Ankrum, Joseph M. Ballantyne, Toby Berger, Henry D. Block, Ralph Bolgiano, Neil M. Brice, Nelson H. Bryant, Robert R. Capranica, Herbert J. Carlin, Brendan S. K. Chang, G. Conrad Dalman, Lester F. Eastman, William H. Erickson, Donald T. Farley, Terrence L. Fine, Jeffrey Frey, Thomas Gold, Juris Hartmanis, Clyde E. Ingalls, Frederick Jelinek, Myunghwan Kim, Walter H. Ku, Charles A. Lee, Richard L. Liboff, Simpson Linke, Ross A. McFarlane, Henry S. McGaughan, Paul R. McIsaac, Charles W. Merriam III, John A. Nation, Benjamin Nichols, Robert E. Osborn, Edward Ott, Christopher Pottle, Edwin L. Resler, Jr., Joseph L. Rosson, Howard G. Smith, Ravindra N. Sudan, George Szentirmai, Chung-Liang Tang, James S. Thorp, Hwa Chung Torng, Norman M. Vrana, Charles B. Wharton, George J. Wolga, Stanley W. Zimmerman

Field Representative
Donald T. Farley, 230 Phillips Hall

MAJOR AND MINOR SUBJECTS
Electrical Engineering
Electrical Systems
Electrophysics

The appropriate major and minor subjects listed above define broad areas in the Field within which a student may plan a graduate program which best suits his needs. In addition to the formal courses listed below, members of the faculty are prepared to guide individual students in special topics and to arrange seminars for students interested in closely related lines of study and research. Proficiency is expected in all phases of the graduate program.

Considerable latitude is allowed in the selection of the minor subjects provided that the entire program shows a unified purpose. Adequate work in advanced physics and mathematics is required of candidates for the degree of Ph.D. At least one of the two minor subjects must be chosen outside the Field of Electrical Engineering. It is possible in some cases to obtain the Ph.D. degree without first obtaining the M.S.

ADMISSION REQUIREMENTS. Though the Graduate Record Examination is not required in this Field, applicants are urged to submit results of this examination with their applications.

As a prerequisite for graduate work leading to the degree of M.S. or Ph.D. with a major in the Field of Electrical Engineering, the candidate should have had the equivalent of the fundamental work required by an accredited undergraduate curriculum in the area of his major subject. The candidate must also supply definite evidence of scholarly interest and aptitude for advanced study.

LANGUAGE REQUIREMENTS. There is no foreign language requirement for the M.S. degree. Candidates for the Ph.D. degree are encouraged to become proficient in at least one modern foreign language. The specific requirement, if any, is left to the discretion of the student's Special Committee.

EXAMINATIONS. The Field of Electrical Engineering requires that every Ph.D. student complete successfully a qualifying examination prior to taking the admission to candidacy examination. For the Master of Science degree a final examination is required. Examinations as required by the Graduate School (see p. 11) are conducted by the student's Special Committee.

FINANCIAL AID. In addition to several University-wide fellowships, the following are available for electrical engineering degree candidates:

John McMullen Graduate Fellowship.

IBM Fellowship.

General Telephone and Electronics Laboratory Fellowship.

National Science Foundation Traineeships. Candidates must be United States citizens.

Michael Faraday and James Clerk Maxwell Fellowships of the Aeronautical Laboratory.

United States Steel Foundation Fellowship. Open only to United States citizens.

Charles Bull Earle Memorial Graduate Fellowship.

Schlumberger Foundation Fellowship. Open to continuing students.

General Electric Fellowship.

There are also a number of teaching fellowships and research assistantships available. In addition, some assistantships are available for summer work.

A prospective degree candidate is invited to direct his inquiries to the Graduate Field Representative for Electrical Engineering, 230 Phillips Hall.

Research Opportunities

The diversity of the interests of the faculty of the Field of Electrical Engineering makes possible a research program which is unusually broad in scope. The various areas of research can be roughly grouped under the headings of Electrical Engineering (general), Electrical Systems, and Electrophysics.

ELECTRICAL ENGINEERING. This area includes electrical measurements; instrumentation; the conversion, transmission, and control of electrical energy; acoustics; and electronic music. Projects in some typical research projects include the design of an electric automobile, a radio deer-tracking system, and a remotely controlled vehicle for exploring planetary surfaces. Other work is closely tied to research work in the systems or electrophysics areas. Laboratory facilities are available for research in any of these fields.

ELECTRICAL SYSTEMS. Research in systems is concentrated in the areas of control theory, information and decision theory, and network analysis and design. Studies of stochastic control, optimization and approximation techniques, distributed parameter systems, and the simulation of systems are applied to process control, vehicle guidance, the optimization of parameters of electromechanical systems, and the study of biological systems. Research in information coding and transmission, random signal processing, decision making, and pattern classification is applied to topics such as speech compression, space communication, radar and sonar problems, and the classification of aerial photographs. Finally, the analysis and synthesis of time-varying, nonlinear, active, and/or distributed parameter networks, and digital and switching circuits, are being applied to the design of various semiconductor devices, broadband matching devices, adaptive matched filters, and computer central processors. A reliance upon mathematical analysis and electronic computers is common to all these areas, and, in particular, computer programs have been developed for network analysis.

ELECTROPHYSICS. This category includes all research in which the primary concern is the interaction of electromagnetic fields with materials in the solid, liquid, gaseous, or plasma state. More specifically, topics with which faculty members are currently concerned include high energy plasmas, geophysical plasmas such as the ionosphere and magnetosphere, radio wave propagation, magnetohydrodynamics, electron beam devices, quantum electronics and lasers, solid state physics, high frequency phenomena in semiconductors, semiconductor devices, and bioelectronics. Extensive experimental facilities are available in all these areas; in particular these include a high-intensity relativistic beam (currents of 200,000 amps, energies of 500 Kev) used in laboratory plasma research and the very large radar facility (antenna diameter of 1,000 feet) operated by Cornell in Arecibo, Puerto Rico, which is used for ionospheric and astronomical studies.

It is neither desirable nor intended that the boundaries between these general areas be rigidly defined. For example, electrical measurements and instrumentation are obviously important in most areas of electrophysics research, and high temperature plasma research requires the careful manipulation of large amounts of electrical energy. Every effort is made to allow each student to pursue a broad program of advanced study tailored to his particular interests. There are no courses which all students are required to take, and work in such fields as applied physics, astronomy, computer science, biological science, engineering materials, fluid mechanics, or thermodynamics may be considered as partially fulfilling the requirements for a major or minor in Electrical Engineering, even though these subjects are not under the direct jurisdiction of the faculty of the School of Electrical Engineering.

Professional Degree

The Master of Engineering degree is the only professional engineering degree offered by Cornell University. Admission to the Master of Engineering (Electrical) degree program is open to persons who have been granted Bachelor's degrees, or the equivalent, and who have sufficient training to indicate that they can profitably study the advanced courses offered for these students in the School of Electrical Engineering. The purpose of this degree program is to offer depth of study in both comprehensive and specialized electrical engineering subjects, and to offer study extending the abilities of the electrical engineer to other areas.

In addition to the general requirements for the degree (see p. 8), a further requirement for the M.Eng. (E.) is a minimum of two sequences of two courses each in advanced electrical engineering (chosen from a designated list). However, Cornell graduates granted fifteen hours of advanced standing for courses taken as undergraduates (see p. 26) can take six credit hours in the School of Electrical Engineering instead of two sequences of two courses each; the design requirement may also be waived in these cases.

Elective and Graduate Courses

Of the following senior elective and graduate courses, certain ones may not be offered every year if the demand is considered to be insufficient.

Theory of Systems and Networks

4450 Bioelectric Systems. Spring term. Credit three hours. Three lectures. Prerequisite: 4401 or Biological Sciences 423 or Physics 360 or equivalent.

The course deals with the application of electrical systems techniques to biological problems. Electrical activity of nerve cells; generation and propagation of nerve impulse; voltage clamp technique, Hodgkin-Huxley model, and its phase plane analysis; electrical excitability and transfer function of neuromuscular systems; synaptic transmission; models of nerve cells and control system analysis of oscillatory activity. Nerve nets: I. evoked activity; II. spontaneous activity; III. simulation and computer analysis. Functional neuroanatomy of brain; transfer characteristics of sensory receptors; sensory encoding and processing in the peripheral and central nervous systems; neural mechanisms for vision and hearing.

4503 Theory of Linear Systems. Fall term. Credit four hours. Three lectures. Prerequisite: 4401 or consent of the instructor.

The state-space model for linear systems. Properties of ordinary linear differential equations. Fundamental and transition matrices. Matrix exponential functions, the Cayley-Hamilton theorem and the Jordan form. Time-invariant and time-varying network and system response. Controllability, observability, stability. Realizability of linear causal systems and applications of Fourier, Laplace, Hilbert transforms. Paley-Wiener theorem. Distributed systems. At the level of Schwarz and Friedland, *Linear Systems.*

4504 Theory of Nonlinear Systems I. Spring term. Credit four hours. Three lectures. Prerequisite: 4503 or 4501 or 4571 or consent of the instructor.

Analysis of first- and second-order nonlinear systems with applications. Phase plane analysis of autonomous systems; singular points, limit cycles, and equilibrium states; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; perturbation theory, existence, convergence, and periodicity of perturbation series; the methods of van der Pol, and Krylov and Bogoliubov. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically excited systems.

4507–4508 Random Processes in Electrical Systems. Fall and spring terms. Credit four hours. Three lectures.

The concepts of randomness and uncertainty and their relevance to the design and analysis of electrical systems. An axiomatic characterization of random events. Probability measures, random variables, and random vectors. Distribution functions and densities. Functions of random vectors. Expectation and measures of fluctuation. Moment and probability inequalities. Properties and applications of characteristic functions. Modes of convergence of sequences of random variables: laws of large numbers and central limit theorems. Kolmogorov consistency conditions for random processes. Poisson process and generalizations. Gaussian processes. Covariance stationary processes, correlation functions, spectra; Bochner and Wiener-Khinchin theorems. Continuity, integration, and differentiation of sample functions. Hilbert space approach to optimum filtering and prediction. Spectral representation, orthogonal series representations. Markov chains and processes. Linear and nonlinear transformations of random processes.

4571 Network Analysis. Fall term. Credit four hours. Three lectures.

Introduction to network topology. Network formulation for computer-aided analysis. State-space techniques for time-invariant and time-varying networks. Scattering, immittance, hybrid formalisms. Nonreciprocal and active network properties. Scattering and realizability theorems for multiport networks. At the level of *Network Theory: An Introduction to Reciprocal and Non-Reciprocal Circuits* by Carlin and Giordano.

4572 Network Synthesis. Spring term. Credit four hours. Three lectures. Prerequisite: 4571 or 4503 or consent of the instructor.

Physical basis for network techniques in lumped and distributed systems deduced from linearity, time-invariance, and power-energy constraints. Generalized bounded real and positive real functions and matrices and the theory of physical realizability. Applications to insertion loss synthesis, synthesis of n-ports, design of transmission line filters, and equalizers. RC-lines. Gain band-width theory of active devices. Synthesis of active networks.

Electromagnetic Theory

4511 Electrodynamics. Fall term. Credit four hours. Three lectures, one recitation. Prerequisite: 4312 or equivalent and coregistration in Math 421 or equivalent.

Foundations of electromagnetic theory. Maxwell's equations, electromagnetic potentials, and integral representations of the electromagnetic field. Special theory of relativity. Radiation of accelerated charges and Cherenkov radiation. Electrodynamics of dispersive and anisotropic media. Normal modes of waveguides and cavities. Surface waves and leaky waves.

4514 Microwave Theory. Spring term. Credit four hours. Three lectures, one recitation. Prerequisite: 4511 or equivalent.

Introduction to microwave theory and its application to passive devices. Propagation in electromagnetic and acoustic waveguides. Scattering theory for junctions including resonant cavities and directional couplers. Gyrotropic media and nonreciprocal devices. Perturbation theory, coupled mode theory, and applications of symmetry techniques.

4567 Antennas and Radiation. Spring term. Credit three hours (four hours with laboratory). Three lectures: laboratory (optional). Prerequisite: 4312, 4401 or equivalent.

Formulation of the electromagnetic field in terms of vector and scalar potentials; radiation from elemental electric and magnetic dipoles. Linear radiators; radiation from short dipoles, small loops; resonant wire antennas; long wire antennas, linear arrays and pattern synthesis; impedance properties of wire antennas, including mutual impedance, parasitic elements; wire receiving antennas. Aperture antennas; uniqueness theorem for vector fields, equivalence and induction principles; radiation from open-ended waveguides, horn antennas, reflector antennas; Babinet's principle; slot antennas. At the level of Jordan and Balmain, *Electromagnetic Waves and Radiating Systems.*

Electronics

4431–4432 Electronic Circuit Design. Throughout the year. Credit three hours a term. Two lecture-recitations, one laboratory. Prerequisite: 4322.

Design techniques for circuits used in electronic instrumentation. Circuits will be designed to provide specific functions, then constructed and tested in the laboratory. At the level of *Pulse Digital and Switching Waveforms* by Millman and Taub.

4433 Semiconductor Electronics I. Fall term. Credit four hours. Three lectures, one laboratory. Prerequisite: 4302 and 4322.

Band theory of solids; properties of semiconductor materials; the physical theory of p-n junctions, metal-semiconductor contacts, and p-n junction devices; device fabrication; properties of semiconductor devices such as diodes and rectifiers, light-sensitive and light-emitting devices, field effect and bipolar transistors, unijunction transistors, p-n-p-n devices (diodes, controlled rectifiers and switches), etc.; device equivalent-circuit models; field-effect and bipolar transistor amplifier stages. At the level of Ankrum, *Semiconductor Electronics.*

4434 Semiconductor Electronics II. Spring term. Credit four hours. Three lectures, one laboratory. Prerequisite: 4433.

A continuation of 4433 with emphasis on the application of semiconductor devices as active or passive elements in circuits for use as power supplies, power controls, amplifiers, oscillators and multivibrators, pulse circuits, gates and switches, etc.; transistor noise; integrated circuits.

4435 Electronics and Music. Fall term. Credit three hours. Two lectures.

An introduction to musical acoustics and the application of electronics to production as well as reproduction of musical material. Topics include physical properties of sound, historical development of musical materials, physical properties of musical instruments, speech and hearing mechanisms, electronic terms and concepts, elements of sound-reproducing chains, home and professional audio practices, electronic musical instruments and electronic music composition processes. Outside work will include independent reading and writing of papers on selected topics.

4436 Electronic Processing of Audio Signals. Spring term. Credit three hours. Two lectures. Prerequisite: familiarity with electronics.

A technical introduction to acoustic sources, propagation media, and receptors, and the problem of interfacing electronic equipment with the acoustic environment. Topics include acoustic oscillators, vibrating strings, plasma waves, spherical waves, loudspeakers, microphones, properties of large enclosures, audio amplifiers, circuits, considerations governing signal-to-noise ratio optimization, tape recorder technology, professional audio practices and circuitry, electronic musical instrument circuitry, and electronic music instrumentation. Outside work will include independent reading and the writing of several research reports.

4531 Quantum Electronics I. Fall term. Credit four hours. Three lectures, one recitation-computation. Prerequisite: 4311, 4312 and Physics 443 or 4411.

A detailed treatment of the physical principles underlying optical masers, related fields, and applications. Topics will include: a review of quantum mechanics and the quantum theory of angular momentum; the interaction of radiation and matter; the quantum mechanical density matrix and macroscopic material properties; theory of the laser and maser; characteristics of optical resonators. At the level of *Quantum Electronics* by Yariv, and *Fundamentals of Quantum Electronics* by Pantell and Puthoff.

4532 Quantum Electronics II. Spring term. Credit four hours. Three lectures, one recitation-computation. Prerequisite: 4531 or consent of the instructor.

A continuation of the treatment of the physical principles underlying optical masers and related fields. Topics will include: spectroscopy of free atoms, ions, molecules, semiconductors, and ions in crystals with examples from important optical masers; survey of chemical and dye lasers; electro-optic interactions in solids; parametric and nonlinear processes; the principles of holography. At the level of *Quantum Electronics* by Yariv, and *Fundamentals of Quantum Electronics* by Pantell and Puthoff.

4534 Nonlinear and Quantum Optics. Spring term. Credit four hours. Three lectures, one recitation. Prerequisite: 4531 or Physics 572.

A detailed study of various recent developments in the theory and application of nonlinear and coherent optics. Topics will include: the use of density matrix and quantum field theory in nonlinear optics and the theory of coherence; spontaneous and stimulated Brillouin, parametric, and Raman processes; optical subharmonic and harmonic generation; optical mixing; frequency down- and up-conversion processes; optical parametric oscillator and other nonlinear optical devices. At the level of current published literature on these topics.

4535 Solid State Devices I. Fall term. Credit four hours. Three lectures. Prerequisite: 4412 or equivalent.

A study of the properties of semiconductor devices with emphasis on low-frequency operation (below 1,000 GHz). Devices based on the tunnel effect: tunnel diodes, zener diodes, field emitter cathodes, thin film resistors. Devices based on charge flow across semiconductor-semiconductor contacts: p-n diodes, avalanche diodes, transistors, field effect transistors, unipolar transistors. Devices based on metal semiconductor contacts: Schottky diode, Schottky triode. Emphasis is placed on determining the factors underlying performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. At the level of *Physics of Semiconductors* by Moll (McGraw Hill), and of current papers published in the *IEEE Transactions on Electron Devices.*

4536 Solid State Devices II. Spring term. Credit four hours. Three lectures. Prerequisite: 4551 or equivalent.

A study of the properties of semiconductor devices with emphasis on high-frequency operation (above 1,000 GHz). The analytic approaches to be studied are: ballistic analysis, electronic-network analysis, space-charge wave and coupled-mode analysis. Devices studied include: avalanche microwave diode (Read diode), Gunn oscillators, fast-response photo diodes, and other contemporary devices. Emphasis is placed on factors that determine the performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. At the level of current papers published in the *IEEE Transactions on Electron Devices.*

4537 Integrated Circuit Techniques. Fall term. Credit three hours. Two lectures, one laboratory. Prerequisite: 4412 or equivalent or consent of instructor.

Integrated circuit techniques applicable in the fields of computer, telecommunication, and optoelectronics are covered in this course. The emphasis is on device technology and the device-system interface. Computer logic and memory circuits are discussed, with special interest in monolithic MOS structures. Telecommunication applications concentrate on microwave hybrid integration of avalanche diode and Gunn and LSA oscillators in transmitters and receivers. In optoelectronics, solid state sensor and display panels are treated, particularly incorporating III-V and II-VI compound semiconductor devices. A term project will be carried out by the student. The course is oriented according to the *Proceedings* of recent international solid state circuits conferences and relevant current publications.

4631–4632 The Physics of Solid State Devices. Fall and spring terms. Credit two to three hours per term by permission of the instructor. Two lectures. Prerequisite: 4536 or permission of the instructor.

The analysis of solid state devices of current interest (avalanche, LSA, Gunn devices, etc.) will be considered in sufficient detail to understand some of the limitations of analysis and/or physical understanding that are involved in the design of such devices. Toward this end the relevant scattering mechanisms which affect the transport properties of warm and hot charge carriers and the complications of band structure will be discussed. In order to deal thoroughly with these basic aspects the number of devices considered will be limited, but subjects of specific interest to individuals may be considered on a seminar basis.

Power Systems and Machinery

4441 Contemporary Electrical Machinery I. Fall term. Credit three hours. Two lecture-recitations, one laboratory-computation. Prerequisite: 4302.

Emphasis on engineering principles. Real and reactive power requirements of core materials with symmetrical and with biased magnetizing forces; analysis and characteristic prediction of high-efficiency transformers; magnetic amplifiers, energy transfers among electric circuits, magnetic fields, and mechanical systems; control of magnetic field distribution by reluctance and winding distribution; traveling fields from polyphase excitation; elementary idealized commutator-type, asynchronous, and synchronous machines.

4442 Contemporary Electrical Machinery II. Spring term. Credit three hours. Two lecture-recitations, one laboratory-computation. Prerequisite: 4302.

Emphasis on engineering principles. Production of air-gap magnetic fields; elementary and idealized rotating machines; steady-state and transient characteristics of realistic rotating machines: a-c commutator-type single-phase motors; polyphase synchronous, and single-phase induction machines; recently developed types: Saturistor motor, self-excited a-c generators; miscellaneous rotary devices; hysteresis motor, selsyns, amplidynes, frequency converters.

4443 Power System Equipment. Fall term. Credit three hours. Two lectures, one computation. Prerequisite: 4302 or 4942 or consent of the instructor.

Engineering responsibilities for system equipment and control are studied. Emphasis is placed on producer-user relations for catalog or built-to-order items. Calculations and test requirements for electrical apparatus, and for electrical power production, distribution, and use, are considered. Prime movers, generators and their accessories, switchgear, protective devices, power transformers, converters, towers, conductors, regulating devices, data-gathering and computer-control systems are analyzed. Inspections of nearby plants and equipment supplement classroom work.

4444 High-Voltage Phenomena. Spring term. Credit three hours. Two lectures, one computation. Prerequisite: 4302 or 4942 or consent of the instructor.

Problems of the normal operation of power systems at very high voltages are studied. The abnormal conditions imposed by lightning and the methods employed to assure proper operation are considered. Laboratory testing of equipment under actual or simulated conditions, being an essential step in the engineering design of high-voltage apparatus, is emphasized. Considerable attention is given to dielectric behavior, traveling-wave and dielectric testing techniques. Electrical manufacturing test facilities are visited.

4445–4446 Electric Energy Systems I and II. Fall and spring terms. Credit four hours per term. Three lecture-recitation-computations. Prerequisite: 4322 or 4942 and consent of the instructor.

The physical and engineering principles underlying steady-state and transient operation and control of modern electric power systems, with emphasis on the characteristics of major power system parameters. Theory of electromechanical energy converters, power transformers, conventional transmission lines and cables, high-voltage-direct-current systems, power networks and other power system components; use of the digital computer as a dynamic "laboratory" model of a complex power system for load-flow, fault, transient stability and economic-analysis studies. Laboratory-computing periods will include selected experiments with electromechanical energy converters. At the level of Stevenson, *Elements of Power System Analysis,* 2nd Edition.

Radio and Plasma Physics

4461 Wave Phenomena in the Atmosphere. Fall term. Credit three hours. Three lecture-recitations. Prerequisite: 4302 and 4312.

An elementary treatment of wave phenomena in the atmosphere of the earth including gravity waves, planetary waves, acoustic waves, radio waves, and plasma waves; attention is directed to the role of these phenomena in various atmospheric processes and engineering problems, such as weather, pollution, radio communication, atomic fallout.

4462 Radio Engineering. Spring term. Credit three hours. Three lecture-recitations. Prerequisite: 4312 and 4401.

A study of electrical systems for communication, control, detection, and other purposes, in which radiowaves (wireless) play a central role; system functions, including generation, modulation, transmission, reception, and demodulation; guidance, radiation, and propagation of radiowaves, including transmission lines and waveguides, antenna systems, and the effects of atmospheric inhomogeneity; system design problems.

4464 Elementary Plasma Physics and Gas Discharges. Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 4312 or equivalent.

Review of electromagnetic wave theory and applications. Gas discharges and arcs; positive column, collisions, mobility, diffusion, breakdown, sheaths, DC and RF excitation, transition from glow to arc, Langmuir and conductance probes, reflex discharge, effects of magnetic field. Plasma as a dielectric medium, interaction of electromagnetic waves (e.g., microwaves) with plasma in free space and in finite regions. Plasma oscillations, spacecharge waves, cyclotron harmonic radiation, Tonks-Dattner resonances, effects of plasma temperature. At the level of Heald and Wharton, *Plasma Diagnostics with Microwaves.*

4551–4552 Upper Atmosphere Physics I and II. Fall and spring terms. Credit three hours each term. Three lectures. Prerequisite: 4312 or equivalent.

The physical processes governing the behavior of the earth's ionosphere and magnetosphere will be considered. Topics covered will include the production, loss, and transport of charged particles in the ionosphere and magnetosphere; temperature variations; airglow; tidal motions, winds, and gravity waves in the ionosphere; the electrical conductivity of the ionosphere, the dynamo current system, and the equatorial and auroral electrojets; the interaction between the magnetosphere and the solar wind; the acceleration and drift of energetic particles in the magnetosphere; the precipitation of particles and the aurora; magnetic and ionospheric storms. At the level of Rishbeth and Garriott, *Introduction to Ionospheric Physics*.

4561 Introduction to Plasma Physics. Fall term. Credit three hours. Three lectures. Prerequisite: 4311 and 4312 or equivalent.

Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles, and macroscopic instabilities; test particle in a plasma; elementary applications. At the level of Longmire, *Elementary Plasma Physics*.

4564 Advanced Plasma Physics. Spring term. Credit three hours. Three lectures. Prerequisite: 4561.

Boltzmann and Vlasov equations; moments of kinetic equation, Chew-Goldberger-Low theory, waves in hot plasmas, Landau damping, instabilities due to anisotropies in velocity space, gradients in magnetic field, temperature and density, etc.; effects of collisions and Fokker-Planck terms; high-frequency conductivity and fluctuations, quasi-linear theory; nonlinear wave interaction, weak turbulence and turbulent diffusion.

4565 Radiowave Propagation I. Fall term. Credit three hours. Three lectures. Prerequisite: 4312 and 4401 or equivalent.

Propagation in the earth's environment: the troposphere, ionosphere, magnetosphere, and interplanetary space. Diffraction and surface wave propagation; tropospheric refraction and ducting; propagation in the ionospheric plasma including magnetoionic theory, the CMA diagram, cross-modulation and Faraday rotation, whistler mode propagation, ion effects and ion whistlers, group velocity and ray tracing, WKB solutions of the coupled wave equations.

4566 Radiowave Propagation II. Spring term. Credit three hours. Three lectures. Prerequisite: 4565 or equivalent.

Full wave solutions of the coupled wave equations; interactions between particles and waves in the magnetosphere; radar astronomy; the scattering of radio waves from random fluctuations in refractive index; tropospheric and D region ionospheric scatter propagation, incoherent scatter from the ionosphere and its use as a diagnostic tool, radio star and satellite scintillations and their use in studying the ionosphere and solar wind.

4661 Kinetic Equations. Spring term. Credit three hours. Three lectures. Prerequisite: Physics 561 and 562, or permission of the instructor.

Designed for students wishing a firm foundation in fluid dynamics, plasma kinetic theory, and nonequilibrium statistical mechanics. Brief review of classical dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analysis of the BBKGY sequence. Chapman-Kolmogorov analysis of Markovian kinetic equations. Derivation of fluid dynamics. Kinetic formulation of the stress tensor, Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Klimontovich formulation. Coarse graining and ergodic theory. At the level of Liboff, *Introduction to the Theory of Kinetic Equations.*

Communications, Information and Decision Theory

4472 Introduction to Algebraic Coding. Spring term. Credit three hours. Three lectures. Prerequisite: Math 293 or equivalent.

A course studying the design and analysis of codes for correction or detection of errors in digital data processing transmission. Encoding and decoding algorithms and their implementation. Properties of linear sequential machines and feedback shift registers. The underlying algebraic theory (groups, finite fields, etc.) will be developed from start as needed. The codes studied will include: group block codes, Hamming codes, Bose-Choudhuri codes, cyclic codes, convolutional tree codes, Reed-Muller codes. Majority logic (threshold) decoding and sequential decoding.

4501 Systems with Random Signals and Noise. Fall term. Credit four hours. Three lectures, one recitation. Prerequisite: 4402 or consent of the instructor.

Signal processing, linear, linear time-invariant (LTI), and memoryless nonlinear transformations; causal and noncausal LTI systems; bounds on LTI signal-processing systems; signal representation, orthogonal expansions, low-pass and band-pass signals and systems, analytic signals; probability, random variables, limit theorems, random vectors, and transformations of random vectors; introduction to random processes, stationary processes, correlation and power spectra; linear and memoryless nonlinear transformations of random processes; models for noise in physical systems, noise factor, and noise temperature; selected topics in nonlinear processing of random signals.

4502 Statistical Aspects of Communication. Spring term. Credit four hours. Three lectures, one recitation. Prerequisite: 4501 or consent of the instructor.

Deterministic signals in additive noise, applications to radar detection, radar system parameters and design topics; system optimization, matched filters, matched filter realizations, signal design; linear smoothing and prediction of stationary processes, causal and noncausal filters, design topics for causal filters; modulation systems, performance of analog systems in time and frequency multiplex with additive noise; digital modulation systems, PCM systems with additive noise; optimum processing of digital data, signal design for digital transmission, decision rules and design of decision-oriented receivers, error bounds; selected topics in hypothesis testing and parameter estimation applied to receiver design.

4673 Principles of Analog and Digital Communication. Fall term. Credit four hours. Three lectures. Prerequisite: 4508 or consent of the instructor.

Uses the fundamentals of information theory, signal theory, and statistical estimation and decision theory to formulate approaches to the solution of problems arising in digital and analog communication. Particular topics include: receiver and signal design, probability of error, capacity, threshold effects for the additive Gaussian channel. Extensions to the additive Gaussian channel: feedback, random gain and phase, diversity. Time-variant Gaussian channels; receiver and signal design, probability of error, and capacity. At the level of Viterbi, *Principles of Coherent Communication.*

4674 Transmission of Information. Spring term. Credit four hours. Three lectures. Prerequisite: 4507 or Math 571 or consent of the instructor.

Applies information theory to the analysis and design of communication systems. Selection of fidelity criteria for accurate and efficient transmission of information. Efficient representation of outputs of message sources. The entropy measure and its properties. Encoding for reliable communication through discrete memoryless noisy channels. Rate of information transmission and the probability of decoding error, channel capacity. Systematic codes and the instrumentation problems. Sequential decoding. Coding and decoding for the band-limited Gaussian channel. Coding of sources with a fidelity criterion. At the level of Jelinek, *Probabilistic Information Theory.*

4676 Decision and Estimation Theory for Signal Processing. Fall term. Credit four hours. Three lectures. Prerequisite: concurrent registration in 4507 or Math 571.

An examination of selected decision and estimation problems encountered in the design and analysis of radar/sonar target-discrimination, signal-demodulation, and pattern-classification systems. The hypotheses of risk and uncertainty, the role of objectives, criteria for evaluating decision or estimation procedures, and characteristics of such procedures. Additional topics, drawn from the fields of parametric and nonparametric statistics, empirical time-series analysis, and nonprobabilistic decision or estimation procedures, will be treated as required for the resolution of the selected problems.

4672 Foundations of Inference and Decision Making. Spring term. Credit three hours. Three lectures. Prerequisite: a course in probability and some statistics, or consent of the instructor.

An examination of methods for characterizing uncertainty and chance phenomena and for transforming information into decisions and optimal systems. Discussion of the foundations of inference centers on various approaches to the interpretation and formalization of probability, including: axiomatic systems of comparative probability; Kolmogorov system of quantitative probability; relative frequency interpretations; computational complexity, randomness and probability; classical probability and invariance; logical probability and induction; subjective probability and personal decision making. Discussion of the foundations of decision making will center on utility theory; axiomatic rationality; statistical decision theory; the nature of a good system; recent work on system design when there is little prior information.

Computing Systems and Control

4481–4482 Feedback Control Systems. Fall and spring terms. Credit three or four hours per term. Three lectures, one optional laboratory. Prerequisite: 4302 or consent of the instructor.

The analysis of feedback control systems, and synthesis techniques to meet specifications or minimize performance indices. Mathematical models of physical systems and solution of differential equations by the Laplace transform; transfer functions. The state-space approach to control systems; observability, controlability. Analysis and synthesis of linear control systems by root locus and frequency response methods. Nonlinearities in control systems; analysis and compensation using describing functions and the phase-plane; Lyapunov stability. Sampled-data systems and digital compensation. An introduction to parameter optimization and optimal control. Laboratory work consists of familiarization with system components and correlation of transient and frequency responses;

synthesis of linear and optimal control systems, and analysis of nonlinear and sampled-data systems using analog and digital computers.

4483 Analog Computation. Fall term. Credit four hours. Two lectures, one laboratory. Prerequisite: concurrent registration in 4401 or equivalent background with consent of the instructor.

Concepts and principles of analog computation and simulation as applied to engineering analysis and design. Linear, time-varying, and nonlinear differential equations. Automatic iterative and basic optimization techniques using digital logic. Laboratory work with general-purpose analog computers. Course develops fundamental ideas to include subjects at the level of Levine, *Methods of Solving Engineering Problems Using Analog Computers.*

4484 Analog-Hybrid Computation. Spring term. Credit three or four hours by permission of the instructor. Two lectures, one laboratory. Prerequisite: 4483.

Theory, design, characteristics, and programming of analog-oriented hybrid computer systems; analog-digital computer linkage systems; error analysis and error compensation in hybrid computation; theory and laboratory work on automatic iterative procedures, steepest descent programs, parameter optimization and parameter identification methods. The laboratory will make use of an analog computer linked with digital logic components. At the level of Bekey and Karplus, *Hybrid Computation.*

4487–4488 Switching Theory and System. Fall and spring terms. Credit three or four hours per term. Three lectures, one optional laboratory. Prerequisite: Math 293–294 or equivalent; first term prerequisite to second.

Mathematical foundation, switching devices, logical formulation and realization of combinational switching circuits; function minimization and decomposition, fault detection and diagnosis; implementation algorithms; threshold logic; number representation and codes; iterative network; simple memory devices; synchronous and asynchronous sequential circuit, regular expression; circuit equivalence; decomposition theorems and algorithms for secondary assignments; hazards in switching circuits; logic design of general-purpose digital computers.

Topics for the optional laboratory session: design and construction with solid-state modules of counters, shift registers, adders, other arithmetic circuits in a digital computer, and general sequential networks.

4505 Approximation Techniques. Fall term. Credit four hours. Three lectures. Prerequisite: 4402 or consent of the instructor.

Approximation techniques used in the synthesis of systems and signals, with applications in control and communication. Signal approximation problems; Kautz filters, measurement of expansion coefficients, complementary filters. Examples of signal approximation problems in biological and electrical systems. Optimal pole positions for exponential approximation. Computational methods for parameter optimization and approximation problems.

4506 Optimization Techniques. Spring term. Credit four hours. Three lectures. Prerequisite: 4503 or consent of the instructor.

Optimization techniques used in the synthesis of systems, with applications in control. Formulation of deterministic control optimization problems; minimal time, minimal fuel, regulator problems. Introduction to variational methods. Solution of two-point boundary-value problems by control vector iteration. Synthesis of optimal feedback controllers.

4588 Bionics and Robots (Theoretical and Applied Mechanics 1857). Spring term. Credit three hours. Two lectures, one recitation. Prerequisite: elementary differential equations, linear algebra and probability, or consent of the instructor.

Interactions between engineering and biology. The mechanization of biological functions such as learning, seeing, hearing, recognition, recall, instinctual behavior, theorem proving, game playing, navigating, exploring, cognition, homeostasis, optimization, adaptation to natural environments, heuristic reasoning, language acquisition and translation, self-organization, self-reproduction, and self-repair, embryogenesis, growth, evolution, and ecology. Cybernetics, information, reliable systems from unreliable components. Models: hardware, simulation, analysis. Neural nets, perceptrons, threshold logic, madelines, features in patterns. Artificial intelligence. Computers and the foundations of mathematics. Turing machines, computability, algebraic linguistics, Gödel's theorem, the Euler-Diderot metatheorem.

4681 Random Processes in Control Systems. Fall term. Credit four hours. Three lectures. Prerequisite: 4574 and 4584.

Prediction and filtering in control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, generalized Wiener filtering, stochastic optimal and adaptative control problems. Selected topics: Bayes decision rule, min-max policy, maximum likelihood estimate, control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; stability of control systems with random parameters.

General

4421–4422 Advanced Electrical Laboratory. Fall and spring terms; may be taken consecutively or separately. Credit four hours. One lecture, two laboratories. Prerequisite: 4322 or consent of the instructor.

Advanced experiments concerning a wide range of topics appropriate to electrical engineering, and lectures concerning experimental techniques and practical aspects of electronics. About thirty different experiments are available concerning topics of transistor and tube amplifiers, feedback, class-C amplifiers and oscillators, gyrators, doubletuned circuits, push-pull amplifiers, multivibrators, operational amplifiers, switching systems, oscillator synchronization, noise properties, microwave circuits, microwave propagation and scattering, semiconductor properties such as the hall effect and minority carrier mobility, helicone waves, Gunn and avalanche diode oscillators, lasers, propagation of electromagnetic waves, antennas, and a-c and d-c machines. The student is expected to perform three or four experiments per term, selected to meet his needs. Emphasis is placed upon independent work.

4591–4592 Project. Fall and spring terms. Credit three hours.

Individual study, analysis, and usually experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing his project; an engineering report on the project is required.

4593 Fundamentals of Acoustics. Fall term. Credit four hours. Three lectures, one laboratory.

Vibrations in strings, bars, membranes, and plates; plane and spherical acoustic waves; transmission, reflection, absorption, resonators, filters; loudspeakers and microphones; speech, hearing, and noise; architectural acoustics; ultrasonic and sonar transducers; underwater acoustics. At the level of Kinsler and Frey, *Fundamentals of Acoustics.*

4595–4596 Electrical Engineering Design. Fall and spring terms. Credit three hours per term.

For students enrolled in the M.Eng.(E.) program. Utilizes real engineering situations in which to present fundamentals of engineering design.

4691–4692 Electrical Engineering Colloquium. Fall and spring terms. Credit one hour per term. Tuesday 4:30–6.

For graduate students enrolled in the Field of Electrical Engineering. Lectures by visiting authorities, staff, and graduate students. A weekly meeting for the presentation and discussion of important current topics in the Field.

4790–4800 Special Topics in Electrical Engineering. Either term. Credit one to three hours.

Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

Environmental Quality

Faculty

B. E. Dethier, N. C. Dondera, L. B. Dworsky, A. W. Eipper, C. D. Gates, L. S. Hamilton, A. W. Lawrence, R. C. Loehr, D. P. Loucks, D. C. Ludington, W. R. Lynn, R. T. Oglesby, G. W. Olson, D. Pimentel, H. W. Seeley, Jr., J. C. Thompson, Jr., P. J. Zwerman

Field Representative

R. C. Loehr, 207 Riley-Robb Hall

MINOR SUBJECT

Environmental Quality

This Field offers qualified engineers and scientists an opportunity to broaden their knowledge in physical, chemical, and biological areas related to environmental quality problems and their control at the same time as they increase their depth of knowledge in their own disciplines. This minor is intended to encourage interdisciplinary study, and students selecting it will take courses in several disciplines with the objective of understanding the environment and its interaction with man.

The environmental quality minor will represent for each student that combination of courses, seminars, and projects which, in the judgment of his committee, is most likely to meet his needs and the comprehensive aspects of the minor.

M.S. CANDIDATES. It is suggested that a student seeking a Master's degree take a minimum of three courses for this minor, with the courses being given in at least two areas outside his major field.

PH.D. CANDIDATES. It is suggested that a student seeking a doctoral degree take a minimum of five courses for this minor, with the courses being given in at least two areas outside his major field.

Geography

Students interested in graduate work in geography will find study programs in many aspects of this subject in several Fields described in this *Announcement.* Graduate degrees are not offered in the subject of geography as such, but advanced study in geography is made possible by informally combining study in the constituent elements of the subject by arrangement with faculty members listed below.

Agricultural Geography: Professor J. W. Mellor
Climatology: Professor Bernard E. Dethier
Geological Sciences: Professor George A. Kiersch
Land Economics: Professor Howard E. Conklin
Development Sociology: Professor Olaf F. Larson
Sociology: Professor J. Mayone Stycos
Soil Science: Professor Marlin G. Cline

Correspondence with members of the faculty in the student's special subject of interest is encouraged.

Geological Sciences

(Geology, Geochemistry, Geophysics, Geobiology, Physical Geography, Applied Fields)

Faculty
Joseph W. Berg, Jr., Arthur L. Bloom, Bill Bonnichsen, Kenneth F. Clark, George A. Kiersch, Shailer S. Philbrick, John W. Wells

Field Representative
George A. Kiersch, 140 McGraw Hall

MAJOR SUBJECTS

Areal and Environmental Geology
Engineering Geology
Geohydrology and Hydrogeology
Geomorphology
Geochemistry, Mineralogy-Petrology
Geophysics
Geobiology, Paleontology, and Stratigraphy
Mineral Deposits, Mining Geology
Physical Geography
Structural Geology and Geomechanics

MINOR SUBJECTS. All of the major subjects in this Field can also be taken as minor subjects by students in other Fields. Other areas in the Field are sedimentation, Pleistocene geology, water resources, and geological oceanography. Majors and minors in many specialized interdisciplinary areas of geological science are also available (see p. 97).

ADMISSION REQUIREMENTS. Candidates with a major in this Field will be expected to offer for admission an A.B. degree or its equivalent. Students with undergraduate majors other than geology, such as physical sciences or engineering, may be admitted with the expectation that deficiencies in the geological sciences at the undergraduate level will be rectified soon after admission so that all students in this program will then have the equivalent of the course work of a Cornell undergraduate major in geological sciences.

Applicants should take the Graduate Record Examination Aptitude Test and Advanced Test in Geology in sufficient time to permit inclusion of the results in the application for admission to the Graduate School.

Aims and Operations of the Field

The program of graduate study in the Field of Geological Sciences is designed to give broad training in both the field and laboratory. Candidates for the Master's degree will take one minor subject, and candidates for the doctorate will take two minor subjects outside the Field of Geological Sciences. Minor subjects may be chosen from many fields, such as agronomy, botany, engineering, chemistry, mathematics, physics, materials science, water resources, zoology, the biological sciences, or nonscientific fields.

Graduate work in Geological Sciences may include investigation under approved direction in localities away from Ithaca and the northeastern states. A brochure about graduate work in Geological Sciences may be obtained by writing to the Field Representative.

LANGUAGE REQUIREMENTS. *Master's degree:* Before the candidate completes the second residence unit, proficiency must be established in one of the following languages: French, German, or Russian. *Doctoral degree:* Before the candidate will be allowed to schedule the final examination on his thesis, proficiency must be established in two of the following languages: French, German, or Russian.

EXAMINATIONS. The Special Committee conducts all examinations required for the degree. At the time of entrance to the Field, a general examination covering the candidate's preparatory training may be given by the faculty to assist in planning a program of study.

Master's degree: A final examination which consists of a comprehensive on the major and minor fields and the thesis is required.

Doctoral degree: A qualifying examination is required in addition to the examinations required by the Graduate School. The qualifying examination will determine the applicant's fitness for undertaking advanced studies and will enable the Special Committee to plan a program which will make the student familiar with the requisite knowledge in his chosen area. It must be taken before the end of the second semester in residence. The Graduate School requires a comprehensive admission to candidacy examination, and a final examination covering the thesis.

DEGREE REQUIREMENTS. *Master's degree:* a minimum of two residence units; proficiency in one language; one minor outside Geological Sciences; submission of thesis; and final examination. *Ph.D. degree:* a minimum of six residence units; proficiency in two languages; a comprehensive admission to candidacy examination on major and two minors outside Geological Sciences; submission and defense of dissertation.

FINANCIAL AID. There are nine graduate teaching fellowships available in the Field of Geological Sciences. Appointments are made for the academic year to supervise laboratory sections, among other duties, for approximately fifteen hours per week. The stipend ranges from $2,700 to $2,800, plus scholarships covering tuition and fees ($2,650) for a total value of $5,350. Full residence credit is given for advanced degrees.

In addition, teaching fellows who are doctoral candidates are eligible for special summer awards of up to $500 to pursue their research projects.

The Eleanor Tatum Long Fellowship, restricted to research in the subject of structural geology and geomechanics, for either Master's or doctoral candidates, carries a stipend of $2,400 and a scholarship covering tuition and fees ($2,650) for a total value of $5,050.

The Department has several special endowments which, at the discretion of the staff, may be used to assist graduate students in their research and field work. Research assistantships are available in certain cases from individual faculty research grants or contracts, either during the summer or the academic year.

The Graduate School administers a number of scholarships and fellowships. Awards are based on scholastic ability and promise of achievement as a graduate student. Besides the Cornell-supported awards, financial aid is offered by foundations and national agencies, e.g., NSF, NDEA, NASA, NIH, and by the State of New York.

Professional Degrees

MASTER OF SCIENCE FOR TEACHERS. A Master of Science for Teachers (Earth Science) program is offered in conjunction with the Department of Science Education; no thesis is required.

MASTER OF ENGINEERING. A program is offered in conjunction with the College of Engineering; no thesis is required. A major in an engineering subject is combined with a sequence of courses in Geological Sciences.

Research and Study Opportunities

The Ithaca region is particularly suited for research in stratigraphy, paleontology, geomorphology, and glacial geology. The nearby Adirondack area is a classic one for studies in metamorphic and igneous petrology. Research projects in structural geology, geomechanics, engineering geology, and hydrogeology are available at field sites in western as well as northeastern states, as are projects in mineral deposits, physical geography, and areal geology. The laboratories of the Department contain standard as well as specialized equipment. Through the cooperating faculty of other departments on campus, every type of special and advanced equipment is available. The well-equipped laboratories and the exceptional libraries provide excellent opportunities for graduate research.

The Department owns outstanding reference collections for teaching and research, such as: the Benjamin Silliman Jr. Collection of minerals acquired in 1868; suites of ores and host rocks from world-wide mining districts; and extensive invertebrate fossils of Paleozoic, Mesozoic, and Cenozoic from throughout the world; as well as the major collection of Recent mollusks (10,000 species) assembled by Wesley Newcomb and purchased in 1868 by Ezra Cornell.

The Paleontological Research Institution, a private research organization, is near the campus, and its facilities are available to the specialized investigator.

The Department has a cooperating agreement with the Museum of Northern Arizona at Flagstaff, for accommodating research projects and investigators. Every conceivable geologic condition and feature is available for study in the region, which constitutes an unusual field setting. The Committee for Labrador Studies has been pursuing research in Labrador for forty years, and projects are in progress on field mapping, glacial geology, and petrography.

For summer research grants in geological science at the Museum of Northern Arizona and elsewhere (after one year at Cornell), consult the Field Representative.

Interdisciplinary Studies

Graduate studies may be pursued in many of the specialized interdisciplinary areas of geological sciences as either a major or a minor at the Master's and doctoral levels, such as:

OCEANOGRAPHY. Oceanography and marine ecology are offered in cooperation with the Division of Biological Sciences and the Department of Conservation. Research projects are in progress in the Long Island coastal areas, and cooperative research is provided with the Woods Hole Oceanographic Institute, Isle of Shoals Station, University of New Hampshire, and the Mote Marine Laboratory, Sarasota, Florida.

WATER RESOURCES. Study in water resources is available through the University's Water Resources Center, with programs to meet individual requirements in the physical, biological, and social sciences, and in engineering.

A professional scientific hydrology program is available for majors in geohydrology in the Geological Sciences.

APPLIED BRANCHES. Programs of study are available in the following branches of applied geological science: mining geology-mineral deposits, petroleum geology, hydrogeology and geohydrology, and engineering geology. The major in a branch of applied geological science has two minors outside the Department in such subjects as soil science, hydraulics, water resources, soil mechanics, materials engineering, mathematics, chemistry, physics, economics, and regional planning.

COOPERATING FACULTY. Many additional interdisciplinary courses are offered by faculty in other departments or divisions, such as paleobotany, ecology-systematics, biogeochemistry, limnology, soil genesis, soil mineralogy, aerial photo analysis, regional planning, hydraulics and hydrology, and materials science and engineering.

Courses

(Students should check this tentative listing with the Department for any changes.)

Geography, Physical

312 Geography of Anglo-America. Spring term. Credit four hours. Prerequisite: Geography 111 or Geology 102. Lectures, M W F 9:05 and additional assigned problems. Staff. Alternate-year course.

The geographic provinces of Anglo-America, their geomorphic expression, climates, resources, development, and interrelationships.

314 Continental Geography. Spring term. Credit four hours. Prerequisite: Geography 111 or Geology 102. Lectures, M W F 9:05 and additional assigned problems. Staff. Alternate-year course.

Physical geography, regional climatology, land use, and natural resources of a selected continent or region.

610 Special Work. Throughout the year. Credit two hours a term. Prerequisite: consent of the instructor. Staff.

Special or original investigations in physical geography on the graduate level.

General Geology (Physical Processes)

322 Structural Geology—Tectonics. Spring term. Credit four hours. Prerequisite: 102 (or 203) and 351; 352 recommended. Lectures, M W 11:15. Laboratory, M 2–4:25, and additional assigned problems. Field trips. Mr. Kiersch.

Nature, origin, and recognition of geologic structures. Behavior of geologic materials, stresses, geomechanical and tectonic principles applied to the solution of geologic problems. Analysis of structural features by three-dimensional methods.

421 Sedimentation. Fall term. Credit four hours. Prerequisite: 352; 441 recommended. Lectures, M W 9:05. Laboratory, T 2–4:25, and additional laboratory work. Field trips. Messrs. Philbrick and Kiersch. Alternate-year course.

Source materials, mechanics of transport and dispersal, depositional environments, lithification and diagenesis of sediments. Analysis of common problems in applied fields due to these phenomena.

441 Geomorphology. Fall term. Credit four hours. Prerequisite: 102. Lectures, T Th 9:05. Laboratory, T 2–4:25, and additional assigned problems. Mr. Bloom.

Description and interpretation of land forms in terms of structure, process, and stage.

444 Geological Oceanography. Spring term. Credit three hours. Prerequisite: 102 or Biological Sciences 461. Lectures, M W F 9:05. Field trips. Mr. Bloom.

Shoreline erosion, transportation, and deposition; origin and structure of continental shelves and ocean basins. Geologic processes and geomorphic development in the marine environment.

542 Glacial and Pleistocene Geology. Spring term. Credit three hours. Prerequisite: 441 or consent of the instructor. Lectures, T Th 9:05. Laboratory, T 2–4:25. Several Saturday field trips. Mr. Bloom.

Glacial processes and deposits and the stratigraphy of the Pleistocene.

Geochemistry

MINERAL MATERIALS AND PROCESSES

351 Mineralogy. Fall term. Credit four hours. Prerequisite: 102 and Chem 108. Lectures, M 10:10. Laboratory, W F 2–4:25. Staff.
Crystallography, crystal chemistry, and systematic mineralogy of the ore and rock-forming minerals.

352 Petrology. Spring term. Credit four hours. Prerequisite: 351. Lectures, M F 10:10. Laboratory, Th 2–4:25 and additional assigned problems. Mr. Bonnichsen.
Composition, classification, and origin of sedimentary, metamorphic, and igneous rocks.

451 Optical Mineralogy. Fall term. Credit four hours. Prerequisite: 351. Lecture, T Th 11:15. Laboratory, F 9:05–12:20, and additional assigned problems. Mr. Bonnichsen.
Use of the petrographic microscope, optical properties of rock-forming minerals, common textures of sedimentary, metamorphic, and igneous rocks.

452 Optical Petrography. Spring term. Credit four hours. Prerequisite: 352 and 451. Lecture, T Th 11:15. Laboratory, F S 9:05–12:20, and additional assigned problems. Mr. Bonnichsen.
Chemical and physical petrogenesis of sedimentary, metamorphic, and igneous rocks in view of field studies, thin section analysis, and experimental petrology.

551 Geochemistry. Fall term. Credit three hours. Prerequisite: 352. Lectures, M W F 8:00. Staff.
Distribution of major and minor elements in the earth, geochemical cycles of the elements, and chemistry of weathering and petrogenesis.

554 X-ray Analysis. Spring term. Credit two hours. Prerequisite: 352. Lecture, W 12:20. Laboratory, F 2–4:25. Staff.
Theory and use of x-ray diffraction and spectroscopy in identification and analysis of minerals, rocks, and soils.

653 Advanced Petrology. Fall term. Credit three hours. Prerequisite: consent of the instructor. Hours to be arranged. Mr. Bonnichsen. Alternate-year course.
Readings and discussions on the petrogenesis of igneous rocks. Laboratory studies of selected igneous rock suites.

656 Advanced Mineralogy. Spring term. Credit three hours. Prerequisite: 452 and 554. Lectures, T Th 9:05. Laboratory, Th 2–4:25. Staff.
A theoretical treatment of the crystal chemistry and thermodynamics of rock-forming minerals.

MINERAL DEPOSITS

461 Mineral Deposits: Metals. Fall term. Credit four hours. Prerequisite: 352. Lectures, M W F 10:10. Laboratory, F 2–4:25. Field trips. Mr. Clark.
Principles and processes involved in the formation of mineral deposits. Modes of occurrence, origin, distribution, and utilization of the major, rare, and minor metals.

462 Mineral Deposits: Nonmetals. Spring term. Credit four hours. Prerequisite: 461 or consent of the instructor. Lectures, M W F 10:10. Laboratory, F 2–4:25. Field trips. Mr. Clark.
Properties, occurrence, associations, distribution, and economic utilization of the industrial minerals and rocks.

563 Ore Microscopy. Fall term. Credit two hours. Prerequisite: 451 and 461. Laboratory, F S 7:30–9:55 a.m. Alternate-year course. Mr. Clark.
Identification of ore-minerals in polished sections which reflect light by etching and microchemical reactions: study and interpretation of mineral relationships.

Geophysics

581 Exploration Geophysics. Fall term. Credit three hours. Prerequisite: Physics 208, Geology 102 or 203; Geology 322 is recommended. Lectures, T Th 9:05. Laboratory, S 10:10–12:35, and assigned problems. Mr. Clark and staff. Alternate-year course.
Elementary theory and interpretation of data from exploration geophysical methods. Environmental geology and selection of techniques for important applied areas.

583 Physics of the Earth. Fall term. Credit three hours. Prerequisite: 322, Math 112, Physics 208. Lectures and laboratory to be arranged. Mr. Berg.
Theory and field measurements of the earth's gravitational, magnetic, seismic, electrical, thermal, and radioactive properties.

584 Seismology. Spring term. Credit three hours. Prerequisite: 583. Lectures and laboratory to be arranged. Mr. Berg.
Theory of stress and strain, seismic wave propagation, earthquake studies, and observational seismology.

586 Seminar in Rock Deformation. Spring term. Credit two hours. Prerequisite: 533 and 583. Time to be arranged. Staff.
Review of stress analysis and behavior of materials, both the rock mass and sample. Fundamentals of deformation pertaining to the crustal rocks and the problems of applied geological science.

Applied Geological Science

532 Hydrogeology. Spring term. Credit three hours. Prerequisite: 322, 352; 441 is recommended. Lectures, M W 9:05. Laboratory, T 2–4:25 and field trips. Mr. Philbrick. Alternate-year course.

Hydrologic cycle and water provinces; occurrence, movement, quantity, and chemical quality of groundwater in porous media. Water resources development.

533 Engineering Geology—Theory and Environments. Fall term. Credit three hours. Prerequisite: 322, 352; 441 is recommended. Lectures, M W 11:15. Laboratory, M 2–4:25 and field trips. Mr. Kiersch.

Advanced study of the physical phenomena and rock properties of special importance from the planning through the operation stages of engineering works; includes underground fluids, subsidence, gravity movement, seismicity, geomechanics and stresses, rock mechanics, weathering, and geologic materials of construction. Analysis of geologic problems encountered in practice; predicting the influence of natural and man-made environmental factors.

535 Engineering Geology—Practice. Fall term. Credit three hours. Prerequisite: 533 or 322–352 and 441. Lectures, M W 9:05. Laboratory, T 2–4:25 and field trips. Mr. Philbrick. Alternate-year course.

Application of geological principles in the planning-design, construction, and operation of engineering works. Case histories, analysis, and evaluation of physical environmental factors, remedial treatment, and reports.

561 Fundamentals of Mining Geology. Fall term. Credit three hours. Prerequisite: 461 and 462. Lectures, M W F 10:10. Assigned problems. Field trips. Mr. Clark. Alternate-year course.

Principles of geological, geophysical, and geochemical techniques used in mineral exploration. Mining geology, guides to ore, mining methods.

562 Economics of Mineral Deposits. Spring term. Credit three hours. Prerequisite: 461 and 462; 561 is recommended. M W F 10:10. Assigned problems. Mr. Clark. Alternate-year course.

Sampling and ore estimation. Cutoff, grade, tonnage, and economic factors related to mining and mineral marketing. Financial calculations and procedures used in mineral property valuation.

582 Exploration Geology. Spring term. Credit three hours. Recommended for all graduate students in geological sciences. Prerequisite: graduate standing and field geology. Lectures, M W 9:05. Laboratory, W 2–4:25. Messrs. Philbrick and Kiersch. Alternate-year course.

Methods of exploration and appraisal of geologic data from both field and laboratory investigations. Assessment of environmental geology and the presentation of direct and indirect information for professional purposes and applied fields.

Geobiology (Paleontology and Stratigraphy)

471 Invertebrate Paleontology. Fall term. Credit four hours. Prerequisite: 102 and, if possible, invertebrate zoology. For those interested in fossil evidence of the development of organisms. Lectures, T Th 10:10. Laboratory, W Th 2–4:25. Mr. Wells.

Paleobiology and classification of important fossil invertebrates.

472 Principles of Historic Geology. Spring term. Credit four hours. Prerequisite: 322 and 471. Lectures, T Th 10:10. Laboratory, W 2–4:25, and additional assigned problems. Mr. Wells.

Application of geologic principles to interpretation of earth history; development of the geologic column, geochronology and geochronometry; correlation and the zone concept; sedimentary environments and provinces; geosynclines and platforms; problems of the pre-Cambrian and continental evolution.

571 Stratigraphy: Paleozoic. Fall term. Credit three hours. Prerequisite: 472. Lectures, T Th 9:05 and W 7:30 p.m. Mr. Wells. Alternate-year course.

Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

572 Stratigraphy: Mesozoic and Cenozoic. Spring term. Credit three hours. Prerequisite: 472. Lectures, T W Th 9:05. Mr. Wells.

Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

672 Stratigraphy of New York State. Spring term. Credit three hours. Prerequisite: 571. Lectures, T Th 12:20 early in the term, followed by all-day and weekend field trips. Mr. Wells. Alternate-year course.

The classic Paleozoic sections of New York studied through lectures, readings, and field observation.

Seminars and Special Work

Seminar in Geological Sciences. Each term. No credit. For majors and required of graduate students, but open to all who are interested. T 4:45. Staff and visiting lecturers.

Reports and discussion of current research in the geological sciences.

690 Special Work. Throughout the year. Credit two hours a term. Prerequisite: consent of the instructor.

Advanced work on original investigations in geological sciences.

690-a Analytical geochemistry, crystallography, and mineralogy. Staff.

690-b Petrology and geochemistry of metamorphic and igneous rocks, associated metallic minerals. Mr. Bonnichsen.

690-c Coastal geomorphology and Pleistocene geology. Mr. Bloom.

690-d Engineering geology, geomechanics, and hydrogeology. Mr. Kiersch.

690-e Seismology, crustal and marine geophysics, heat flow. Mr. Berg.

690-f Invertebrate paleontology and paleoecology. Mr. Wells.

690-g Sedimentology and primary structures. Staff.

690-h Physical and engineering geology, water resources. Mr. Philbrick.

690-i Mineral deposits and resources, exploration geophysics. Mr. Clark.

Materials Science and Engineering

Faculty
Dieter Ast, Robert W. Balluffi, Boris W. Batterman, John M. Blakely, Malcolm S. Burton, Paul S. Ho, Joseph O. Jeffrey, Herbert H. Johnson, Edward J. Kramer, Che-Yu Li, Thor N. Rhodin, Arthur L. Ruoff, Henri S. Sack, Stephen L. Sass, Eraldus Scala, David N. Seidman, Benjamin M. Siegel, John Silcox, Floyd O. Slate, Watt W. Webb

Field Representative
Edward J. Kramer, 326 Bard Hall

MAJOR AND MINOR SUBJECTS

Materials Science
Materials and Metallurgical Engineering

ADMISSION REQUIREMENTS. Graduates from any undergraduate engineering or physical science program will be accepted if they have demonstrated marked competence in the basic parts of their studies and show competence, in general, as graduate students. Applicants who lack some of the prerequisites recommended by the Field, but are otherwise qualified, will be allowed to remedy the deficiency by taking undergraduate courses while enrolled as graduate students.

It is recommended, but not required, that applicants present the results of the Graduate Record Examination with their applications.

LANGUAGE REQUIREMENTS. There are no language requirements for the M.S. or Ph.D. degree.

EXAMINATIONS. All examinations required for a degree are administered and reported by the candidate's Special Committee. The examinations may be oral, or written and oral. In accordance with Graduate School legislation, a comprehensive examination is required for admission to Ph.D. candidacy. A thesis examination is given upon submission of the Ph.D. thesis.

For the M.S. degree, an examination is required at the time of submission of the M.S. thesis. At the discretion of the Special Committee, this examination may consider the thesis, or the thesis and course work. Under suitable circumstances, the Master's final examination and the admission to candidacy examination may be combined.

RESEARCH AND STUDY OPPORTUNITIES. Through comprehensive and integrated course programs, participation in formal and informal research seminars, thesis research, and in informal discussions, the graduate programs in Materials Science and Engineering lead to careers either in research and development or in engineering application of materials.

The spectrum of current research programs in the Field is very broad, ranging from problems of immediate technological interest, such as crack propagation in high-strength steels, to considerably more basic investigations in such areas as point defects and superconductivity. Current research includes the following areas of interest.

Mechanical behavior: crack formation and propagation, embrittlement phenomena, fatigue, composite materials, anelasticity, yield and cold drawing of polymers.

Imperfections in solids: point defects, dislocation mechanics, defect interactions, radiation damage, substructure, structural studies of polymers.

Phase transformations: crystal growth, precipitation, martensite, alloy steels, superconductivity, solidification, phase decomposition during sintering.

Surface structure and reactions: solid-liquid and solid-gas interfaces, field ion microscopy, surface diffusion, low energy electron diffraction, crystal nucleation.

High temperature materials: composite materials, refractory metals and alloys, complex compounds, sintering of ceramics.

High pressure studies: creep, diffusion, elastic constants, electrical properties.

Electrical and magnetic behavior: superconductivity, semiconductors, NMR, conduction in oxides and amorphous materials, magnetic domain wall motion, photoconductivity.

Development of advanced experimental techniques: electron microscopy, x-ray, high pressure, crystal growing, purification methods.

More detailed information about course programs and research areas is available upon request.

A strong catalyst for the materials research activities at Cornell has been provided by the Materials Science Center, which is supported by the Advanced Research Projects Agency of the United States government, and with which most of the Field faculty are affiliated. The MSC provides substantial financial assistance for graduate students through research assistantships, new equipment for approved thesis research projects, and, in some cases, technician assistance in performing routine measurements.

A most important contribution of MSC has been the creation and maintenance of central research facilities that are used by both faculty and graduate students. Each central facility is directed by a senior staff member and staffed by trained technicians. The facilities include laboratories for materials preparation, metallography, x-ray diffraction, transmission and scanning electron microscopy, mechanical testing, electronics, high pressure, low temperature, chemical analysis, irradiation and nonmetallic crystal growth.

PROFESSIONAL DEGREE. In addition to the M.S. and Ph.D. programs, the Field also offers the professional degree of Master of Engineering (Materials). The professional program, available to students who have demonstrated suitable proficiency in the area of materials and metallurgy in earning their Bachelor's degree, provides advanced courses designed to enlarge the student's preparation for a career in professional engineering, with less emphasis on research. The program is administered by the Engineering Division of the Graduate School (see p. 26).

Courses

Graduate Core Program

6601 Topics in Thermodynamics and Kinetics. Fall term. Credit three hours.

Generalization of thermodynamics to include nonchemical forms of energy. Statistical nature of entropy. Phase stability. Defect equilibria. Thermodynamics of solutions, surfaces, and interfaces. Reaction kinetics. Diffusion. At the level of Slater, *Introduction to Chemical Physics;* Guggenheim, *Thermodynamics.*

6602 Phase Transformations. Spring term. Credit three hours.

Interfaces between phases. Nucleation theory. Growth theory. Formal theory of nucleation and growth transformations. Spinodal decomposition. Diffusionless transformations. Applications of the theory to specific changes in real materials. At the level of Christian, *Theory of Phase Transformations in Metals and Alloys.*

6603 Crystal Mechanics. Fall term. Credit three hours.

Crystal symmetry. Vector fields and tensor fields. Lattice deformation and fault crystallography. Reversible tensor properties of crystals. Relationships between different tensor properties. Crystal elasticity, elastic waves, and polymer elasticity. Lattice dynamics. Thermophysical properties. Irreversible tensor properties. Coupling of transport phenomena. Higher order effects. At the level of Nye, *Physical Properties of Crystals;* Born and Huang, *Dynamical Theory of Crystal Lattices;* and Smith, *Wave Mechanics of Crystalline Solids.*

6604 Dislocations. Fall term. Credit three hours.

Review of geometrical and strain energy aspects of dislocation theory. Experimental evidence for dislocations. Dislocation strain and stress fields and associated strain energy. Interactions with applied stresses and with other dislocations. Jogs, point defects, and climb. Dislocation sources. Crystallographic aspects such as stacking faults and partial dislocations in specified crystal structures. Grain boundaries. At the level of Hirth and Lothe, *Theory of Dislocations,* and Nabarro, *Theory of Crystal Dislocations.*

6605 Electrical and Magnetic Properties of Engineering Materials. Fall term. Credit three hours. Prerequisite: Physics 454 or consent of the instructor.

Electrical properties of semiconductors. Metallic alloys. Ferromagnetic materials. Superconductivity. Optical and dielectric properties of insulators and semiconductors. Ferrites. At the level of Kittel, *Introduction to Solid State Physics;* Chikazumi, *Physics of Magnetism;* Livingston and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties;* de Gennes, *Superconductivity of Metals and Alloys.*

6606 Mechanical Behavior of Materials. Spring term. Credit three hours.

Geometry of slip in single crystals. Strain hardening. Dislocation dynamical treatment of yield and flow. Interaction of interstitial solute atoms with dislocations. Solution hardening. Two-phase hardening. Time dependent deformation. Dislocation models for cleavage of crystals. At the level of review articles in *Progress in Materials Science* and various conference reports.

6611 Principles of Diffraction. Fall term. Credit three hours. Offered jointly with Applied Physics 8211.

A broad introduction to diffraction phenomena applied to solid-state problems. Production of neutrons and x-rays. Scattering and absorption of neutrons, electrons, and x-ray beams. Diffraction from two- and three-dimensional periodic lattices. Crystal symmetry. Fourier representation of scattering centers and the effect of thermal vibrations on scattering. Phonon information from diffuse x-ray and neutron scattering as well as Bragg reflections. Standard crystallographic techniques for single crystals and powders. Diffraction from almost periodic structures, surface layers, gases and amorphous materials. A survey of dynamical diffraction from perfect and imperfect lattices. Techniques for imaging structural defects. Selected experiments illustrating diffraction effects.

Other Graduate Courses

6553–6554 Project. Fall and spring terms. Credit three hours.

Research on a specific problem in materials or metallurgical engineering, applicable to the M.Eng.(Materials) degree.

6612 Selected Topics in Diffraction. Spring term. Credit three hours. Three lectures. Prerequisite: 6611. Offered jointly with Applied Physics 8212.

The Ewald-von Laue dynamical theory applied to x-ray and high energy electron diffraction in solids. Thermal scattering and measurement of phonon dispersion, frequency spectrum, interatomic force constants, Debye temperatures and vibrational amplitudes. Diffuse scattering, short- and long-range order, precipitation in solids, point defects.

6762 Physics of Solid Surfaces. Spring term. Credit three hours. Three lectures. Offered jointly with Applied Physics 8262.

Equilibrium thermodynamics and statistical mechanics of interfaces. Diffuse interfaces, crystal surfaces, anisotropy and orientation dependence of surface properties, Wulff diagrams. Atomic structure of surfaces in equilibrium. Surface fields, dipoles and defects in insulators. Electronic and vibrational properties of surfaces. Surface barriers and work functions, surface vibrational and electronic states. Kinetic processes at surfaces. Mass and charge transport in the surface region. Condensation and evaporation processes. Experimental techniques: discussion of LEED, FIM, FEM, etc. Materials drawn from research papers and various review articles such as *Progress in Materials Science, Advances in Chemistry, Solid State Physics,* and specialized texts such as Many, Goldstein, and Grover, *Semiconductor Surfaces,* and Kaminsky, *Atomic and Ionic Impact Phenomena.*

6764 Fracture of Materials. Spring term. Credit three hours. Three lectures.

Mechanics of fracture. Griffith theory. Crack tip stresses and strains. Crack tip plasticity. Macroscopic aspects of fracture in crystalline and noncrystalline materials. Dislocation models. Void growth. Special topics such as fatigue, environment and fracture, fracture testing. Materials from conference reports; Tetelman and McEvily, *Fracture of Structural Materials;* Kelly, *Strong Solids.*

6765 Amorphous and Semicrystalline Materials. Fall term. Credit three hours. Three lectures.

Topics related to the science of the amorphous state selected from the following general areas: structure of liquids and polymers; rheology of elastomers and glasses; electrical, thermal, and optical properties of amorphous materials. At the level of Mackenzie, *Modern Aspects of the Vitreous State;* Treloar, *The Physics of Rubber Elasticity;* Shen and Eisenberg, *Glass Transition in Polymers.*

6873 Materials Science for Engineers. Spring term. Credit three hours. Three lectures.

Structure of crystals. Crystal lattice properties. Crystal defects (point, line, planar). Thermodynamics of solids. Diffusion and kinetics (emphasis on defect annealing, e.g., polygonization, recrystallization, grain growth, point defect recovery, etc.). Mechanical properties (role of crystal defects in plastic deformation, creep, fracture). Topics in radiation damage including defect productions, radiation damage annealing, and effect of damage on physical properties.

Mathematics

Faculty
Jon Beck, Israel Berstein, James H. Bramble, Lawrence D. Brown, Stephen U. Chase, Marshall M. Cohen, Robert Connelly, Clifford J. Earle, Roger H. Farrell, Michael E. Fisher, Neal J. Friedman, Wolfgang H. J. Fuchs, Howard Garland, Leonard Gross, Richard S. Hamilton, David W. Henderson, Peter J. Hilton, Kiyosi Ito, Arun Jategaonkar, Peter J. Kahn, Harry Kesten, Jack Kiefer, Anthony W. Knapp, Richard B. Lavine, Simon A. Levin, Stephen Lichtenbaum, G. Roger Livesay, Michael D. Morley, Anil Nerode, Paul Olum, Lawrence E. Payne, Richard A. Platek, C. J. Preston, George S. Rinehart, Alex Rosenberg, Oscar S. Rothaus, Alfred H. Schatz, Robert B. Schneider, Shankar Sen, Leonard S. Silver, Frank L. Spitzer, Robert S. Strichartz, Moss E. Sweedler, Robert J. Walker, Hsien-Chung Wang, William C. Waterhouse, James E. West

Field Representative
W. H. J. Fuchs, 124 White Hall

MAJOR AND MINOR SUBJECTS
Algebra
Analysis
Geometry
Mathematics

Prerequisites for admission are a knowledge of advanced calculus (including both theoretical and applied points of view) and modern algebra.

The Field of Mathematics has set the following language requirements: none for the Master's degree; a reading knowledge of German *or* Russian for the Ph.D. degree. There is no formal French requirement, but books and papers in that language will be freely used in all graduate courses, and students can expect to be called upon to read French mathematical texts.

The Field requires teaching experience of all graduate students as part of the requirements for an academic degree.

Candidates for the Master's degree are expected to obtain some understanding of mathematical thought, ordinarily by taking about twenty-four hours of courses at the graduate level. Qualifications for the Ph.D. degree include a broad acquaintance with the basic subjects of present-day mathematics plus a demonstration of ability to do research in one or more branches of mathematics.

Additional information about courses, thesis and examination requirements, and research in mathematics for the entering graduate student is contained in a booklet entitled *Graduate Work in Mathematics at Cornell,* which may be obtained by writing to: Chairman, Department of Mathematics, White Hall.

All of the three major subdivisions of mathematics (algebra, analysis, and geometry) are well represented at Cornell. The Department is also very strong in logic, probability, and statistics. A detailed listing of the research interests of the members of the faculty will be sent to all who request the booklet, *Graduate Work in Mathematics,* referred to above.

Courses

In all 600-level courses the final grades will be only S or U.

All listings are tentative; students should check with the departmental office for definite listings, times, places, etc.

Of the advanced courses at the 500- and 600-levels listed below, all, except those shown in brackets, were offered during 1969–70. In 1971–72, about the same number of advanced courses will be given, selected from both bracketed and unbracketed courses.

Applied Mathematics and Differential Equations

315 Higher Calculus. Fall term. Credit three hours. Prerequisite: 213 or 293.

Intended for students who have had only three semesters of calculus. It does not prepare a student for 415–416 and will not meet the needs of those graduate students whose work requires really serious application of mathematical methods.

Vector analysis. Ordinary and partial differential equations. Fourier series. Special functions. Laplace transforms. Emphasis is placed on a wide range of formal applications of the calculus rather than on the logical development.

Graduate students who need mathematics extensively in their work and who have had a solid advanced calculus course as undergraduates should take 415–416. If they have not had such an advanced calculus course, they should take 421–422–423. If their preparation is still too weak for this, they should take all or part of 221–222, followed by 421–422–423.

415–416 Mathematical Methods in Physics. Throughout the year. Credit four hours a term. First term prerequisite to second.

Intended for graduate students in physics or related fields who have had a strong advanced calculus course and at least two years of general physics. The course goes very quickly, covering in two semesters slightly more than 421–422–423.

Lectures and problems designed to give a working knowledge of the principal mathematical methods used in advanced physics.

Topics include a brief discussion of some basic notions: metric space, vector space, linearity, continuity, integration. Generalized functions (Schwartz distributions). Fourier series and Fourier integrals. Elementary complex variable. Saddle point method. Linear transformations in finite- and infinite-dimensional spaces. Matrices. Differential operators and integral operators, the equations and eigenvalue problems connected with them, and the special functions arising from them. Elements of group theory. The rotation group and its representations.

421 Applicable Mathematics. Fall term. Credit four hours. Prerequisite: 222, or honors section of 294, or consent of the instructor.
Theorems of Stokes, Green, Gauss. Sequences and infinite series. Fourier series and orthogonal functions. Introduction to complex variables.

422 Applicable Mathematics. Spring term. Credit four hours. Prerequisite: 421 or consent of the instructor.
Continuation of complex variables. Conformal mappings. Harmonic functions. Some special functions. Differential equations. Laplace and Fourier transforms. Asymptotic expansions of functions.

423 Applicable Mathematics. Fall term. Credit four hours. Prerequisite: 422.
Linear operators and integral equations. Calculus of variations. Application to eigenvalue problems. Green's function, and treatment of special problems of mathematical physics.

491–492 Mathematical Economics. Throughout the year. Credit four hours a term. Prerequisite: 222. First term prerequisite to second.
Development and analysis of macroeconomic evolution equations for a Keynesian economy with fixed technology. Value theory. Some topics from microeconomic theory: profit-maximizing theory of the firm, monopolistic competition, consumer behavior. Some topics from economic development theory.

517–518 Ordinary Differential Equations. Throughout the year. Credit four hours a term. Prerequisite: 411–412 and some acquaintance with complex variables, or consent of the instructor. First term prerequisite to second.
Existence and uniqueness. Autonomous systems, with specialization in geometric theory in two dimensions. Linear equations. Stability. Bifurcation theory. Some special functions of mathematical physics, from the viewpoint of equations in the complex domain and the two-point–boundary-value problem.

519–520 Partial Differential Equations. Throughout the year. Credit four hours a term. Prerequisite: some acquaintance with complex variables and advanced calculus or, with consent of the instructor, 423 or 416. First term prerequisite to second.
Classification of partial differential equations. Questions of existence, uniqueness, and continuity of the solutions of typical boundary-value problems. The equations of Laplace and Poisson, principle of the maximum and the mean; the wave equation, heat equation.

521 Elementary Functional Analysis. Fall term. Credit four hours. Prerequisite: 415–416 or 421–422–423 or consent of the instructor.
Elementary set theory and topology, Banach and Hilbert spaces, measure and integration. Graduate students in mathematics should take 613 for functional analysis.

522 Applied Functional Analysis. Spring term. Credit four hours. Prerequisite: 521.
Spectral theorem for bounded operators, spectral theory for unbounded operators in Hilbert space, compact operators, distributions. Applications.

627–628 Seminar in Partial Differential Equations. Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.

[**427–428 Introduction to Differential Equations.** Throughout the year. Credit four hours a term. Prerequisite: 222 or 294 or consent of the instructor.]

[**619–620 Advanced Partial Differential Equations.** Throughout the year. Credit four hours a term. Prerequisites: 512 and 613 or consent of the instructor.]

Analysis

411–412 Introduction to Analysis. Throughout the year. Credit four hours a term. Prerequisite: 222. (There will be a special Honors section of this course. The instructor should be consulted.)
An introduction to the theory of functions of real variables, stressing rigorous logical development of the subject rather than technique of applications. Topics include elementary topology, the real number system, continuous and differentiable functions, integration, convergence and approximation theorems. Fourier series, calculus in several variables and differential forms.

413 Introduction to the Theory of Functions of One Complex Variable. Spring term. Credit four hours. Prerequisite: 222 or 312. Some previous acquaintance with advanced calculus, as presented in 411, is definitely helpful.

A rigorous introduction to complex variable theory. Intended mainly for undergraduates and for graduate students outside mathematics; graduate students in mathematics desiring a first course in complex variables should take 511–512. Complex numbers. Differential and integral calculus for functions of a complex variable including Cauchy's theorem and the calculus of residues. Elements of conformal mapping. Elements of several complex variables.

511–512 Real and Complex Analysis. Throughout the year. Credit four hours a term. Prerequisite: 412.

First term: set-theoretic preliminaries, abstract integration. Borel measures, Lebesgue measures, L_p spaces, Hilbert spaces, Banach spaces, product spaces, differentiation. Second term: Fourier transforms. Complex variables, harmonic functions, Schwarz lemma, approximation by rational functions, conformal mappings, including Riemann mapping theorem, Weierstrass- and Mittag-Leffler theorems, Jensen's formula, analytic continuation, the modular function, Picard's theorem.

515 Potential Theory. Spring term. Credit four hours. Prerequisite: 512.

Newtonian as well as logarithmic potential, capacity, Green's functions and the Dirichlet problem in Euclidean space. Either applications to function theory, or integral representation theorems, or some probabilistic potential theory.

611–612 Seminar in Analysis. Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.

613 Functional Analysis. Spring term. Credit four hours. Prerequisite: 432 and 511.

Topological vector spaces, Banach and Hilbert spaces, Banach algebras. Additional topics to be selected by instructor.

615 Fourier Analysis. Fall term. Credit four hours. Prerequisite: 511.

An introduction to harmonic analysis and group representations via important special cases: Fourier series and integrals in several variables (abelian groups), spherical harmonics (compact groups) and representations of the Lorentz group (noncompact Lie groups). Emphasis will be on the L^2 theory, and distributions.

623 Several Complex Variables. Fall term. Credit four hours. Prerequisite: 512.

An introduction to the theory of functions of several complex variables. Domains of holomorphy, removable singularities, analytic varieties. Stein manifolds.

[**514 Complex Variable Theory.** Spring term. Credit four hours. Prerequisite: 512.]

[**523 Analysis on Manifolds.** Spring term. Credit four hours. Prerequisite: 512.]

[**528 Variational Methods.** Spring term. Credit four hours. Prerequisite: 413.]

[**617 Analytic Number Theory.** One term. Credit four hours. Prerequisite: 514.]

[**621 Meromorphic Functions.** Fall term. Credit four hours. Prerequisite: consent of the instructor.]

[**622 Riemann Surfaces.** Fall term. Credit four hours. Prerequisite: 512; 531 is desirable.]

Algebra

431–432 Introduction to Algebra. Throughout the year. Credit four hours a term. Prerequisite: 221 or 331. First term prerequisite to second. (There will be a special Honors section of this course. The instructor should be consulted.)

A rigorous introduction to modern algebra. First term: linear algebra. Second term: introduction to algebraic systems such as groups, rings, modules and fields.

531–532 Algebra. Throughout the year. Credit four hours a term. Prerequisite: 432. First term prerequisite to second.

First term: finite groups, field extensions, Galois theory, rings and algebras, tensor algebra. Second term: Wedderburn structure theorem, Brauer group, group cohomology, Ext, Dedekind domain, primary decomposition, Hilbert basis theorem, local rings. Additional topics selected by instructor.

549–550 Lie Groups and Differential Geometry. Throughout the year. Credit four hours a term. Prerequisite: 511 and 531.

Differentiable manifolds. Basic properties of Lie groups and their relationship to Lie algebras. Compact Lie groups, maximal tori, the Weyl group. Theory of Lie algebras over the real and complex fields. The classical groups.

631–632 Seminar in Algebra. Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.

633 Group Theory. Spring term. Credit four hours. Prerequisite: 531.

Representations and characters of finite groups; transfer and induced representations. Applications to structure of finite groups as time permits.

637 Algebraic Number Theory. Fall term. Credit four hours. Prerequisite: 532 or consent of the instructor.

A summary of the algebraic foundations followed by a discussion of some classical problems: class numbers, primes in arithmetic progressions, binary quadratic forms and genera.

639 Lie Algebras. Spring term. Credit four hours. Prerequisite: 532.
Topics in Lie algebras.

[**635 Theory of Rings.** Spring term. Credit four hours. Prerequisite: 532 or 637.]

[**641 Homological Algebra.** Fall term. Credit four hours. Prerequisite: 531.]

[**649 Topological Groups.** Fall term. Credit four hours. Prerequisite: 511 and 531.]

Geometry and Topology

451–452 Classical Geometries. Throughout the year. Credit four hours a term. Prerequisite: 221 or 331 or 431, which may be taken concurrently. First term prerequisite to second.
Axiomatic methods in geometry. Foundations of Euclidean geometry. Non-Euclidean geometry, projective geometry, other geometric theories.

453–454 Introduction to Topology and Geometry. Throughout the year. Credit four hours a term. Prerequisite: 412 and 432 or consent of the instructor.
This is a new course (designed primarily for undergraduate Option I Mathematics majors) which will cover topics in general and algebraic topology, differentiable manifolds, and perhaps some differential geometry.

551 Introductory Algebraic Topology. Spring term. Credit four hours. Prerequisite: graduate standing or consent of the instructor.
The fundamental group and covering spaces. Homology and cohomology theories for complexes and spaces.

552 Differentiable Manifolds. Spring term. Credit four hours. Prerequisite: 511, 531, or their equivalents.
Manifolds and differentiable structures. Tangent, cotangent, and tensor bundles. Exterior calculus. Riemannian structures. Local and global theory of differential equations. Integration on manifolds.

561 Geometric Topology. Fall term. Credit four hours. Prerequisite: graduate standing or consent of the instructor.
Topics from general topology. Introduction to the geometric properties of manifolds.

651–652 Seminar in Topology. Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.

653–654 Algebraic Topology. Throughout the year. Credit four hours a term. Prerequisite: 551 or equivalent.
Duality theory in manifolds, applications, cohomology operations, spectral sequences, homotopy theory, general cohomology theories, categories and functors.

657–658 Advanced Topology. Throughout the year. Credit four hours a term. Prerequisite: 551 or consent of the instructor.
A selection of advanced topics from modern algebraic, differential, and geometric topology. The content of this course varies from year to year.

667 Algebraic Geometry. Fall term. Credit four hours. Prerequisite: 511 and 531.
The theory of algebraic curves. The Riemann-Roch theorem. Projective embeddings. Singularities.

[**655–656 Homotopy Theory.** Throughout the year. Credit four hours a term. Prerequisite: 551.]

[**659 Symmetric Spaces.** Spring term. Credit four hours. Prerequisite: 549–550.]

[**661–662 Seminar in Geometry.** Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.]

[**663 Manifolds.** Throughout the year. Credit four hours a term. Prerequisite: 551.]

Probability and Statistics

472 Statistics. Spring term. Credit four hours. Prerequisite: 371 and knowledge of linear algebra such as is taught in 221. Preliminary examinations will be held at 7:30 p.m. on three dates during the term.
Classical and recently developed statistical procedures are discussed in a framework which emphasizes the basic principles of statistical inference and the rationale underlying the choice of these procedures in various settings. These settings include problems of estimation, hypothesis testing, and large sample theory. (See also descriptions of 473 and 574.)

473 Statistics. Fall term. Credit four hours. Prerequisite: 472 or 574. Preliminary examinations will be held at 7:30 p.m. on three dates during the term.
A continuation of 472 in which emphasis will be placed on experimental designs, nonparametric statistics, multivariate analysis, sequential analysis and multiple decision problems.

571–572 Probability Theory. Throughout the year. Credit four hours a term. Prerequisite: 412.
Properties and examples of probability

spaces. Sample space, random variables, and distribution functions. Expectation and moments. Independence, Borel-Cantelli lemma, zero-one law. Convergence of random variables, probability measures and characteristic functions. Laws of large numbers. Selected limit theorems for sums of independent random variables. Markov chains, recurrent events. Ergodic and renewal theorems. Martingale theory. Brownian motion and processes with independent increments.

571–574 Probability and Statistics. Throughout the year. Credit four hours a term. Prerequisite: 412; 571 prerequisite to 574.

First term: Same as first term of 571–572. Second term: Topics include an introduction to the theory of point estimation, consistency, efficiency, sufficiency, and the method of maximum likelihood; the classical tests of hypotheses and their power; the theory of confidence intervals; the basic concepts of statistical decision theory; the fundamentals of sequential analysis.

Intended to furnish a rigorous introduction to mathematical statistics, the course is prerequisite to all advanced courses in statistics.

575 Information Theory. Spring term. Credit four hours. Prerequisite: 411 or, with consent of the instructor, 416 or 421. Familiarity with at least part of the contents of 571 would be helpful. No prior knowledge of information theory is required, but a modest amount of mathematical maturity is desirable.

Coding theorems and their converses for the principal noisy channels. Sequential decoding. Two-way codes. Coding with a fidelity criterion. Study of the probability of error. Very recent results on channels with arbitrarily varying channel probability functions and on compound channels.

671–672 Seminar in Probability and Statistics. Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.

675 Statistical Estimation. Fall term. Credit four hours. Prerequisite: 574.

Randomization, sufficiency, completeness, minimum variance estimators. Derivation of sequential minimax estimators by the methods of differential inequalities. Bayes solutions, and invariance. The Neyman-Pearson theory of testing hypotheses and interval estimation.

676 Decision Functions. Spring term. Credit four hours. Prerequisite: 675.

Wald's theory of decision functions. Multidecision problems. Existence theorems, complete class theorems, and other general decision theoretic results. Optimum character of the sequential probability ratio test. Recent developments.

[**673 Analysis of Variance.** Fall term. Credit four hours. Prerequisite: 572 and 432.]

[**674 Design of Experiments.** Spring term. Credit four hours. Prerequisite: 673.]

[**677–678 Stochastic Processes.** Throughout the year. Credit four hours a term. Prerequisite: 511 or 522, 571 or consent of the instructor. First term prerequisite to second.]

[**679 Seminar in Mathematical Economics (Economics 685).** Spring term. Credit four hours. Prerequisite: consent of the instructor.]

Mathematical Logic

581 Logic. Fall term. Credit four hours. Prerequisite: 432 or consent of the instructor.

Basic topics in mathematical logic including: propositional and predicate calculus; formal number theory and recursive functions; completeness and incompleteness theorems.

681–682 Seminar in Logic. Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor.

684 Recursion Theory. Spring term. Credit four hours. Prerequisite: 581 or consent of the instructor.

Theory of effectively computable functions. Classification of recursively enumerable sets. Degrees of recursive unsolvability. Applications to logic. Hierarchies. Recursive functions of ordinals and higher type objects. Generalized recursion theory.

687 Set Theory. Fall term. Credit four hours. Prerequisite: 581 or consent of the instructor.

Models of set theory. Theorems of Gödel and Cohen, recent independence results.

690 Supervised Reading and Research. Variable credit.

[**683 Model Theory.** Fall term. Credit four hours. Prerequisite: 581 or consent of the instructor.]

[**685 Metamathematics.** Spring term. Credit four hours. Prerequisite: 581 or consent of the instructor.]

Mechanical Engineering

Faculty
Donald L. Bartel, John F. Booker, Arthur H. Burr, Bart J. Conta, Terrill A. Cool, David Dropkin, George B. DuBois, Howard N. Fairchild, Benjamin Gebhart, Roger L. Geer, Frederick C. Gouldin, Allan I. Krauter, Sidney Leibovich, Howard N. McManus, Jr., Franklin K. Moore, Richard M. Phelan, Dennis G. Shepherd, Kenneth E. Torrance, Robert L. Wehe

Field Representative
David Dropkin, 214 Upson Hall

MAJOR SUBJECTS
Machine Design
Thermal Power
Thermal Processes

MINOR SUBJECTS
Machine Design
Materials Processing
Thermal Power
Thermal Processes

The graduate Field of Mechanical Engineering is composed of two departments: the Department of Mechanical Systems and Design, which is in charge of the teaching of machine design and materials processing subjects, and the Department of Thermal Engineering, which is in charge of the teaching of thermal power and thermal processes subjects.

Considerable latitude is allowed in the selection of the minor subjects. It is generally expected, however, that a major in thermal engineering will be combined with a minor from some other department. Appropriate minor subjects, such as mathematics, nuclear engineering, electrical engineering, aerospace engineering, mechanics, etc., may be taken in other divisions of the University.

ADMISSION REQUIREMENTS. The applicant for study leading to the degree of M.S. or Ph.D. in this Field should hold a Bachelor's degree and should have the equivalent of the fundamental work required in an accredited undergraduate curriculum in the area of his major work. Those lacking some of the necessary subject matter may be required to take one or more undergraduate courses or do assigned work to make up the deficiency.

LANGUAGE REQUIREMENTS. There is no foreign language requirement for the M.S. degree. For the Ph.D. degree a candidate must demonstrate reading ability in one language in addition to his native language. The required language shall be chosen from French, German, Russian, or others to be approved by petition to the Field.

EXAMINATIONS. A final comprehensive examination is required for the M.S. degree. For the Ph.D. degree the student must take: (a) a qualifying examination (this may be combined with the examination for the M.S.); (b) the admission to candidacy examination, a general examination of subject matter taken approximately at the time he completes his course work; and (c) a final examination primarily concerned with the dissertation.

FINANCIAL AID. In addition to the fellowships and scholarships that are available to all students in open competition, the following are restricted to M.S. and Ph.D. candidates majoring in this Field: Esso Education Foundation Fellowship, John McMullen Graduate Fellowship, Procter and Gamble Fellowship, George Burr Upton Fellowship, Edgar J. Meyer Scholarship, Sibley Scholarship. (See pp. 13–15.)

Opportunities for Study and Research

MECHANICAL SYSTEMS AND DESIGN. Unique instruction is offered in design and related subjects, including materials processing. The thesis and courses may be concentrated in one of the following areas or may overlap them: (1) design and development of a new machine, component, or system; (2) analysis of an existing machine, component, or system; (3) experimental investigation to determine design data and machine or tool performance.

The Department has its own laboratories for stress, vibration, and endurance testing of machine parts, and for the study of controls. It is particularly well equipped for studies of lubrication phenomena in journal bearings, and for studies requiring use of analog computers. The materials processing laboratory includes many special production machines and gaging devices, and instrumentation for tool forces and temperatures.

Interests of the design staff are necessarily broad, and they overlap in a number of cases. However, based on current activities, they include the following areas of special interest.

Lubrication: John F. Booker, Robert L. Wehe.

Manufacturing engineering: George B. DuBois, Robert L. Geer.

Product design: George B. DuBois, Allan I. Krauter.

Design optimization and reliability: Donald L. Bartel, Allan I. Krauter, Howard N. McManus.

Design of components: Arthur H. Burr, Richard M. Phelan.

Vibration and controls: John F. Booker, Richard M. Phelan, Robert L. Wehe.

Computer-aided design: Donald L. Bartel, John F. Booker.

Students who major or minor in machine design usually take their other work in engineering mechanics, materials, materials processing, control systems and servomechanisms, mathematics, thermal engineering, agricultural engineering, or industrial engineering. Those minoring in materials processing may take supplementary studies in the Department of Materials Science and Engineering.

THERMAL ENGINEERING. There are excellent opportunities for both analytical and experimental studies in thermal engineering. The approved major and minor subjects are in two areas of special interest to the staff.

Under the subject of thermal processes, studies may be carried out in three areas: (1) fluid dynamics, including high-temperature and nonequilibrium effects, viscosity, radiative transfer, flow lasers, rotating fluids with application to the confinement of high temperature gases and also natural processes in the atmosphere and oceans, problems of heat rejection to the environment-thermal pollution, air pollution, and plasma processes: Terrill A. Cool, Frederick C. Gouldin, Sidney Leibovich, Franklin K. Moore, Kenneth E. Torrance; (2) heat transfer, including stability of convective flows, two-phase flows, boiling heat transfer, ablative heat transfer, combustion processes and fire research: David Dropkin, Benjamin Gebhart, Howard N. McManus, Jr., Kenneth E. Torrance; (3) thermodynamics including aspects of classical statistical, and irreversible thermodynamics of concern in present-day technology: Bart J. Conta, Terrill A. Cool.

Under the heading of thermal power, studies may be made of direct energy conversion, propulsion and nuclear power problems, use of solar energy, turbomachinery, combustion engines, air conditioning and refrigeration, and heat pumps: Bart J. Conta, David Dropkin, Howard N. Fairchild, Frederick C. Gouldin, Dennis G. Shepherd.

Instrumentation and equipment are available for the study of thermal processes and performance of engineering components and systems. In addition to the customary instruments, such as spectrometers, oscillographs, potentiometers, hot-wire anemometer, etc., the laboratory possesses a large Mach-Zehnder Interferometer of very high precision, a plasma arc generator capable of producing plasmas with high enthalpies and temperatures up to 25,000°F, and a solar collector apparatus suitable for thermal radiation studies. Several fans and compressors are available for a range of air flows, together with a gas-fired steam generating unit.

By his choice of minor subject or subjects, the thermal engineering major may study at an advanced level in basic sciences, such as mathematics, physics, and chemistry, or in related engineering areas, such as aerospace engineering, chemical engineering, electrical engineering, applied physics, materials science, and theoretical and applied mechanics. The graduate student will ordinarily find it desirable to enroll in a number of the elective courses offered in the Department of Thermal Engineering, and he will be expected to participate in Department seminars attended by students, staff, and visitors.

Professional Degree

The degree of Master of Engineering (Mechanical) is available as a curricular type of professional degree, the general requirements for which are stated in the *Announcement of the College of Engineering.* Of the thirty credit hours required, the mechanical engineering program allows nine elective hours, together with considerable latitude in the choice of a laboratory course and the design project. In this way, an option is possible in a particular area, e.g., machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, thermal environment, thermal power, thermal processes, manufacturing engineering, material removal, etc.

The M.Eng.(Mech.) degree may be earned in a minimum of two terms of full-time study by successful completion of the course requirements.

Courses

3090, 3091 Mechanical Engineering Design Project. Fall and spring terms respectively. Credit three hours a term. Intended for students in the M.Eng.(Mech.) program. Staff.

Design of an engineering system or a device of advanced nature. Projects to be carried out by individual students or by small groups with individual assignments, culminating in an engineering report by each student.

3361 Advanced Mechanical Analysis. Fall term. Credit three hours. Three recitations. Prerequisite: 3322 or 3331. Intended for students in the M.Eng.(Mech.) program.

Advanced topics in mechanical design. Selected topics from design optimization, design reliability, advanced kinematics, systems analysis, computer-aided design, advanced strength of materials.

3363 Mechanical Components. Spring term. Credit three hours. Three recitations. Prerequisite: 3325 or equivalent. Mr. Burr.

Advanced analysis of machine components and structures. Application to the design of new configurations and devices. Lubrication theory and bearing design. Fluid couplings, torque converters, speed-control devices. Shell, thick-cylinder, and elastic-foundation theory and design of pressure vessels, rotating disks, and fits. Elastic-plastic design, thermal stresses, creep and relaxation. Impact.

3364 Design for Manufacture. Fall term. Credit three hours. Two recitations, one design or laboratory period. Prerequisite: 3322 or 3331 and 3431 or equivalent, or permission of the instructor. Mr. DuBois.

Principles and methods of design to improve the producibility of machines and products. Design techniques to simplify and improve the processing operations, to reduce cost, and to increase accuracy and reliability. Designs and operation sequences for small-lot and large-lot manufacture to exploit the capabilities inherent in machine tools, jigs and fixtures, and other production equipment. Applications of the foregoing by design exercises.

3366 Advanced Kinematics. Fall term. Credit three hours. Two recitations, one computation. Prerequisite: 3321 or 3331.

Advanced analytical and graphical determination of velocities and accelerations in mechanisms. Special geometrical concepts on the kinematics of mechanisms. Synthesis of linkages by graphical and analytical methods. Design of linkages to give prescribed paths, positions, velocities, and accelerations.

3368 Mechanical Vibrations. Spring term. Credit three hours. Two recitations, one laboratory. Prerequisite: 3324 or equivalent. Mr. Phelan.

Further development of vibration phenomena in single- and multi-degree-of-freedom linear and nonlinear systems, with emphasis on engineering problems involving analysis and design. Also gyroscopic effects, branched systems, random vibrations, impact and transient phenomena, isolation of shock vibration, and noise and its reduction. Impedance, matrix, and numerical methods. Analog and digital computer solutions and laboratory studies.

3372 Experimental Methods in Machine Design. Fall term. Credit three hours. One recitation, two laboratories. Prerequisite: 3322 or 3331. Mr. Phelan.

Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration, and sound measurements, and development techniques are studied as applied to machine design problems.

3374 Conceptual Design. Fall term. Credit three hours. Three recitations. Prerequisite: 3322 or equivalent. Mr. DuBois.

Conception and initial design of products and machines. Methods to stimulate mechanical ingenuity and improve appearance. Principles of synthesis and creativity employing association, inversion, and other techniques. Sketching, class discussion, and comparative evaluation of solutions.

3378 Automatic Control Systems. Spring term. Credit three hours. Two recitations, one laboratory. Prerequisite: 3324 or equivalent. Mr. Krauter.

Further development of feedback control theory, including stability criteria, frequency response, and transfer functions, with emphasis on engineering problems involving the analysis of existing control systems and the design of systems to perform specified tasks. Also, nonlinear systems, describing functions, sampled-data systems, and compensation techniques. Analog computer simulation and laboratory studies of hydraulic, pneumatic, and electromechanical components and systems.

3380 Design of Complex Systems. Either term. Credit three hours. Two meetings of two hours per week. Intended for graduate students in engineering. Permission of instructor required. Mr. Wehe.

A seminar course relying heavily on student participation in discussing frontier problems such as systems for space and underwater exploration, salt water conversion, and transportation. Determination of specifications for these systems to meet given needs. Critical discussion of possible solutions based on technical as well as economic and social considerations. Reports will be required containing recommendations and reasoning leading to these considerations.

3382 Hydrodynamic Lubrication. Spring term. Credit three hours. Three recitations. Mr. Booker.

Designed to acquaint those having a general knowledge of solid and fluid mechanics with the special problems and literature currently of interest in various fields of hydrodynamic lubrication. General topics include equations of viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant films, bearing system dynamics, digital and analog computer solutions. Also selected special topics in elastohydrodynamic, thermohydrodynamic, and magnetohydrodynamic lubrication.

3385 Optimum Design of Mechanical Systems. Fall term. Credit three hours. Three recitations. Mr. Bartel.

The formulation of design problems frequently encountered in mechanical systems as optimization problems with emphasis on the choice of the design objective function and the constraints. Finite and infinite dimensional design problems. Theory and application of methods of mathematical programming to the solution of optimum design problems. Examples to be drawn from structures and machine components frequently encountered in mechanical systems.

3387 Dynamics of Vehicles. Fall term. Credit two hours. Prerequisite: 1021 and 1031 or equivalent and permission of instructor. Mr. Krauter.

Selected topics in vehicle dynamics with emphasis on the articulated vehicle. Development of nonlinear equations for a tractor-semitrailer. Discussion of tire behavior, safety devices, and the fifth wheel. Application to jackknifing. Linear representation and stability. Also, automobile handling, suspension, and safety.

3388 Simulation and Analysis of Dynamic Systems. Spring term. Credit three hours. Three recitations. Mr. Booker.

Some introductory acquaintance with systems dynamics and digital programming areas is assumed. Modeling and representation of physical systems by systems of ordinary differential equations in vector form. Applications from diverse fields. Simulation diagrams. Analog and digital simulation by direct integration. Problem-oriented digital simulation languages (e.g., CSMP). Digital analysis of stability and response of large linear systems. At the level of Chen and Haas, *Elements of Control System Analysis,* Part II, and Conte, *Elementary Numerical Analysis.*

3451 Material Removal Systems. Fall term. Credit three hours. One lecture, two laboratories. Prerequisite: 3431 and Materials Science 6316. Mr. Geer.

Advanced study of mechanics of chip formation. Forces and power dynamometry. Orthogonal and three-dimensional relationships. Cutter geometry and chip control. Nonchip techniques using chemical, electrical, ultrasonic, and other media; surface characteristics; and postprocess treatments.

3475 Numerical Control of Processes. Spring term. Credit three hours. Two lectures, one laboratory-computation. Prerequisite: 3431. Mr. Geer.

A thorough study of concepts, systems, and component designs for flexible-programmed processing. Machine tools as related to numerical control. Machine command-response factors, stick-slip, resonance, shaft windup, mass-inertia, and other effects. Positioning control systems and coding. Manual and computer programming. Simulation studies.

3652 Combustion Theory. Spring term. Credit three hours. Three lectures. Prerequisite: 3625 or equivalent and some familiarity with statistical and classical thermodynamics. Mr. Torrance.

Application of fluid mechanics, thermodynamics, and heat and mass transfer to combustion processes. Topics include chemical kinetics and transport properties; dissociation and heat of combustion; flames in homogeneous mixtures and diffusion flames; ignition, quenching and burning limits; flame propagation and stabilization; deflagrations, detonations, and explosions; burning of droplets and particles. At a level between Strehlow, *Fundamentals of Combustion,* and Williams, *Combustion Theory.*

3654 Refrigeration and Air Conditioning. Spring term. Credit three hours. Prerequisite: 3625, or 3625 concurrently. Mr. Fairchild.

Introduction to refrigeration and air conditioning with emphasis on applications of thermodynamics, fluid mechanics, and heat transfer. Compression and other systems of refrigeration; control of the physical environment.

3656 Advanced Thermal Engineering Laboratory. Both terms. Prerequisite: 3053 or equivalent.

A course of individually offered experimental studies prepared and supervised by faculty of Thermal Engineering, and elected by students. The time allotted, and number of students accepted for each experiment will be specified by the instructor in each case. Available experiments will range from performance testing of engine components to studies of laser interferometry. List for each term furnished by professor in charge.

3659 The Nature of Thermodynamics. Fall term. Credit three hours. Three recitations. Prerequisite: a course in thermodynamics and permission of the instructor. Mr. Conta.

A study of the history, philosophy, and mathematics of thermodynamics with emphasis upon its scope and limitations. A study of the methods of exposition of the concepts and laws of thermodynamics; comparison of the intuitive, the axiomatic, and the statistical approaches. The course will be principle- rather than problem-oriented and each student will be expected to develop a special topic in thermodynamics, present it orally, and write a term paper in place of a final examination.

3661 Equilibrium Thermodynamics. Fall term. Credit three hours. Three lectures. Prerequisite: 3621 and 3622 or equivalent. Mr. Conta.

A general treatment, at an intermediate level, of equilibrium thermodynamics from both the classical and statistical viewpoints. An axiomatic treatment of classical thermodynamics with emphasis upon the mathematical developments and philosophical interpretations. Equilibrium, availability, and irreversibility. The statistics of ensembles, thermodynamic probability, and the partition functions. Statistical thermodynamics; the connections between the two viewpoints. Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac statistics. Systems of noninteracting particles, an introduction to systems of interacting particles, and the transition from quantum to classical statistics.

3663 Turbomachinery. Fall term. Credit three hours. Three recitations. Prerequisite: 3621 and 3623 or permission of the instructor. Mr. Shepherd.

Aerothermodynamic design of turbomachines in general, followed by consideration of specific types; fans, compressors, and pumps; steam, gas, and hydraulic turbines. Energy transfer between a fluid and a rotor; flow in channels and over blades. Compressible flow, three-dimensional effects, surging and cavitation. Outline design of a high-performance compressor-turbine unit.

3665 Transport Processes. Fall term. Credit three hours. Three recitations. Prerequisite: basic thermodynamics and fluid mechanics. Mr. Gebhart.

Description of basic microscopic modes of thermal and mass diffusion. Molecular transport mechanics in gases. Formulation of the transport equations and their application to engineering problems. Conduction and mass diffusion in solids, boundary value problems. Thermal radiation between opaque surfaces in vacuum and as a diffusion process in nonopaque media. Mass and energy diffusion by molecular and by eddy processes in convection. Analytical methods in convection investigated, limits shown, and the role of correlations discussed.

3667 Techniques of Thermal Measurement. Spring term. Credit three hours. Two lectures, one laboratory. Prerequisite: 3625. Mr. Dropkin.

Theory, construction, calibration, and application of liquid-in-glass thermometers, solid expansion thermometers, pressure-spring thermometers, resistance thermometers, thermoelectric thermometers; temperature-sensitive coatings; optical pyrometers; total radiation pyrometers, enthalpy probes, heat flux probes.

3671 Aerospace Propulsion Systems. Spring term. Credit three hours. Three recitations. Prerequisite: 3621 and 3623, or permission of the instructor. Mr. Shepherd.

Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion.

3672 Energy Conversion. Spring term. Credit three hours. Three lectures. Prerequisite: 3621 or equivalent. Mr. Conta.

Primarily an analysis of energy conversion devices from a classification into heat engines, chemical engines, and expansion engines. An analysis of each class from the point of view of efficiency and other criteria of performance. A more detailed study of some conventional and some direct energy conversion devices including thermoelectric, thermionic, and photovoltaic converters; and fuel cells. Energy sources and energy storage, applications to terrestrial and space power systems.

3674 Flowing Gas Lasers. Fall term. Credit three hours. Three lectures, laboratory. Prerequisite: 3623, Physics 443 or consent of the instructor. Mr. Cool.

A comprehensive treatment of the principles of operation of continuous-wave chemical lasers, fluid-mixing lasers and gasdynamic lasers. Opportunity for experimental laboratory studies of a high-power, purely chemical DF-CO_2 laser. Topics covered include: fluid mechanics of the production of population inversions by rapid mixing, chemical reaction, detonation waves, and Prandtl-Meyer expansion; vibrational energy transfer processes in chemical and molecular lasers; chemical kinetics of atom-exchange reactions; chain reaction mechanisms; gain saturation and power output characteristics of high-speed flow lasers; optical design of transverse-axis flow laser resonators; survey of current developments in flowing gas lasers; laser-induced fluorescence spectroscopy.

3675 Dynamics of Rotating Fluids. Fall term. Credit three hours. Three lectures. Prerequisite: Aerospace Engineering 7301 and Theoretical and Applied Mechanics 1182, or consent of the instructor. Mr. Leibovich.

Review of classical fluid mechanics. Rotating coordinate systems. Linearized theory for rapidly rotating fluids. Inviscid regions, viscous layers. Large amplitude steady motions past objects. Unsteady motions. Small amplitude waves. Wave motion in anisotropic, dispersive media. Phase and group velocity. Kinematic wave theory and energy propagation. Nonlinear waves in rotating fluids. "Vortex breakdown" in tornados and other swirling flows. Theories of vortex breakdown. Boundary layer interactions. Spin-up of fluids in rotating containers. This is a theoretical course designed for engineers and scientists interested in such applications as fluid motions in rotating containers, geophysical fluid mechanics, energy and mass separation in vortex tubes, etc. Some simple laboratory demonstrations of fundamental phenomena are included.

3676 Applications of Fluid Mechanics. Spring term. Credit three hours. Three recitations. Prerequisite: 3623 or equivalent. Mr. Moore.

A descriptive survey of fluid mechanics, organized according to application. Acoustics, flight aerodynamics, aircraft stability and performance, propulsion problems, shocks, detonations and blast waves, hypersonic entry, droplets, oceanography and marine systems, biofluid mechanics, and aspects of meteorology and astrophysics are considered. Midterm and final reports are required, each treating in depth a topic chosen by the student.

3677 Numerical Methods in Fluid Flow and Heat Transfer. Fall term. Credit two hours. Two lectures. Prerequisite: Aerospace Engineering 7301 or 3665 or familiarity with the partial differential equations of fluid mechanics; Computer Science 311 or some familiarity with basic FORTRAN programming. Mr. Torrance.

Finite-difference methods for solving problems in fluid flow and heat transfer are developed. Steady and unsteady states; two- and three-space dimensions. Physical and numerical restraints imposed on the numerical solutions are considered. Recent methods are discussed and compared. Application to problems in natural convection, flow over solid bodies and within channels, meteorology. Final examination requires solution of a fluid flow problem on a digital computer. At the level of Richtmyer and Morton, *Difference Methods for Initial-Value Problems,* but with greater physical emphasis.

3680 Advanced Convection Heat Transfer. Spring term. Credit three hours. Three recitations. Prerequisite: 3665 or consent of the instructor. Mr. Gebhart.

Processes of transport of thermal energy, momentum, and mass in fluids are considered in detail. Theories of transfer processes and analytic solutions. Analytical and experimental results compared. Transport equations for a fluid, delineation of kinds of processes, differential similarity, natural convection, mixed convection, forced convection at low and high velocities. Boundary layer solutions, similarity theories, and effects of turbulence. Transport in rarefied gases.

3682 Seminar in Heat Transfer. Spring term. Credit three hours. Two meetings of two hours per week. Prerequisite: permission of the instructor. Mr. Gebhart.

Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions.

Medical Sciences

Graduate School of Medical Sciences

(See p. 29 of this *Announcement.)*

Requests for additional information regarding the Fields in the Medical Sciences should be addressed to: Professor Julian R. Rachele, Assistant Dean, Graduate School of Medical Sciences, Cornell University, Medical College, 1300 York Avenue, New York, N.Y. 10021.

Biomathematics

A new program of applied mathematics in biology is offered by the Biomathematics Division to students whose primary interests are mathematical or theoretical, but who wish to concentrate on biological applications. Programs leading to the Ph.D. degree are flexible to suit the particular area of biological application of the individual student, and appropriate courses of study in the relevant aspects of biology, chemistry, physics, and medicine are planned accordingly.

Biophysics

Graduate work toward the Ph.D. degree in biophysics and the M.S. in radiation physics is offered, as well as opportunities for postdoctoral research in biophysics. Active research programs are being conducted in fundamental radiation biophysics, including cellular radiobiology, and in the biophysics of membrane transport.

Biostatistics

The graduate biostatistics program offered by the Biomathematics Division applies the quantitative methods of the theory of probability and statistics to biological or medical problems. The use of modern computers is an integral part of the program which leads to the Ph.D. degree.

Nuclear Science and Engineering

Faculty
K. Bingham Cady, David D. Clark, Trevor R. Cuykendall, David Dropkin, Charles D. Gates, Vaclav O. Kostroun, Simpson Linke, Raphael M. Littauer, Ross McPherson, George H. Morrison, Mark Nelkin, Robert L. Von Berg

Field Representative
Ross McPherson, Ward Laboratory

MAJOR SUBJECTS
Nuclear Science
Nuclear Engineering

MINOR SUBJECT
Nuclear Engineering

ADMISSION REQUIREMENTS. A Bachelor's degree in science or engineering, including one year of advanced calculus and a one-year course in atomic and nuclear physics, is required. Students with less preparation may be admitted if their undergraduate performance is outstanding, but they should expect to take longer to complete the degree requirements. Applicants who are United States citizens are normally expected to apply for the Atomic Energy Commission Special Fellowships in Nuclear Science and Engineering.

LANGUAGE REQUIREMENTS. For the Ph.D. degree, a reading knowledge of one language other than English is required. There is no language requirement for the M.S. degree.

EXAMINATION REQUIREMENTS. Before the beginning of his second term of graduate study, the student is expected to form his Ph.D. Special Committee. This committee will normally be composed of (1) a chairman, who will be the student's major adviser, (2) a faculty member representing a minor subject outside the Field, and (3) a second member of the Field faculty appointed by the Field Representative. Additional members representing other minor subjects are permitted. As soon as it is formed, the Committee will administer an informal oral examination designed primarily to guide the course of the student's future study and research. Before the end of the fifth term of graduate study, the Committee will administer the admission to candidacy examination, which is both written and oral, and covers the core of the graduate course program. Advanced courses in special topics will be taken by most students after this examination, but the passing of this examination signifies a shift in primary emphasis from course work to research.

FINANCIAL AID. In addition to the Cornell University awards, there are special fellowships for students in nuclear science and engineering that are awarded nationally by the United States Atomic Energy Commission and by the National Science Foundation. Application materials for AEC support may be obtained from the Fellowship Office, Oak Ridge Associated Universities, Box 117, Oak Ridge, Tenn. 37830. Applications are usually due early in January. Applications for NSF fellowships, normally due early in December, are made directly to NSF on forms obtainable from the National Science Foundation, Fellowship Office, National Research Council, 2101 Constitution Avenue, Washington, D.C. 20037.

Applications for admission received before February 1 are automatically reviewed for Cornell fellowship awards. AEC traineeships and teaching and research assistantships may be awarded any time of year as available.

RESEARCH AND STUDY OPPORTUNITIES. Research in nuclear physics and reactor physics requires a knowledge of a number of scientific and engineering disciplines. The organization of the graduate program encourages this kind of interdisciplinary study.

Basic research in low energy nuclear physics and reactor physics at Cornell is centered at the facilities of the Ward Laboratory. In addition to students in Nuclear Science and Engineering, these facilities are used by students from other fields who are performing related research. The major facilities and some typical uses of the facilities are: (1) A TRIGA reactor with a steady state power of 100 kilowatts and a pulsing capability of up to 250 megawatts. The reactor is a source of neutrons and gamma rays for activation analysis, solid and liquid state studies, and nuclear physics. In addition to standard pneumatic and mechanical transfer systems, the reactor is equipped with a 40-millisecond rapid transfer system in one of the six-beam ports which allows study and use of radionuclides having a relatively short half-life. (2) Cornell Critical Facility, a "zero power reactor" of very versatile design for basic studies in reactor physics and dynamics. Equipment ancillary to the reactor includes a pulsed 14 MeV neutron generator used for studies of reactor transients. (3) Subcritical assemblies for reactor physics investigations. (4) Gamma Cell, a shielded cell with a nominal 10,000-Curie Co^{60} gamma-ray source for radiation chemistry and radiation damage studies. The cell is complete with viewing window and remote manipulators which allow experimental versatility within the cell. (5) 3 MeV Dynamitron, a positive ion accelerator of high current capability for atomic and nuclear structure studies and high intensity monoenergetic neutron production.

Faculty research interests are listed below.

K. Bingham Cady: nuclear engineering, reactor physics.
David D. Clark: nuclear structure.
Trevor R. Cuykendall: nuclear engineering.
David Dropkin: heat transfer, thermal processes.
Charles D. Gates: nuclear environmental engineering.
Vaclav O. Kostroun: nuclear and atomic structure.
Simpson Linke: energy conversion.
Raphael M. Littauer: nuclear instrumentation, pulse electronics.
Ross McPherson: nuclear structure.
George H. Morrison: nuclear chemistry.
Mark Nelkin: neutron scattering, transport and kinetic theory.
Robert L. Von Berg: radiation chemistry, chemical engineering.

Research groups in nuclear science are currently pursuing studies of nuclear structure, analytical nuclear chemistry, and theoretical studies related to neutron transport. Examples of current experimental research topics include: the study of short-lived isomers produced by the intense neutron flux of the pulsed TRIGA reactor; the structure of light nuclides studied by using particle reactions at the 3 MeV accelerator; and activation analysis of meteoritic and geological samples using the TRIGA reactor and high resolution gamma-ray spectrometry apparatus. Recent theoretical studies include: slow neutron inelastic scattering from liquids and kinetic theory of time-dependent correlation in fluids.

Current examples of research in nuclear engineering include: basic reactor dynamics; pulsed neutron experiments in multiplying media; theory and measurement of neutron importance; space-dependent reactor kinetics and noise analysis; stochastic theory of neutron transport; thermionic energy conversion; and radiation chemistry.

The detailed program of studies is not prescribed as a curriculum, but is planned by each individual student and the faculty members of his Special Committee. There is, however, a common core of subject matter for study in this Field. This includes the material covered in 8309, 8312, and 8351 as listed in the following pages, a knowledge of applied mathematics through Mathematics 416 or 423, a knowledge of theoretical physics including the graduate quantum mechanics course, Physics 572, and at least one two-term graduate course sequence in some area of engineering. Students majoring in nuclear engineering will also take additional courses from the following list. Students majoring in nuclear science will normally take additional courses in physics at the graduate level.

PROFESSIONAL DEGREE. The Master of Engineering (Nuclear) program is a two-term program intended for students who want either a terminal degree or an interim degree before doctoral study in Nuclear Science and Engineering. The program develops the basic principles of nuclear reactors and shows a student how his field of undergraduate specialization may be applied to nuclear engineering problems. The recommended entrance requirements include: (1) a Bachelor's degree in engineering, applied science, or its equivalent; (2) physics, including atomic and nuclear physics; (3) mathematics, including advanced calculus; and (4) thermodynamics.

Students should make every effort to complete the entrance requirements before beginning the program; this may be done in some cases by informal study during the summer. For further information write to: Nuclear Engineering Field Representative, Ward Laboratory.

Courses

8303 Introduction to Nuclear Science and Engineering. Fall term. Credit three hours.

A lecture and seminar course providing an introduction to nuclear engineering and low-energy nuclear physics for students majoring in other Fields. The objective is to relate the experience of students in other fields to nuclear science and engineering. Topics include: systematics of nuclear structure; properties of nuclear radiations; nuclear fission and the neutron chain reaction; and the classification and uses of nuclear reactors.

8309 Low-Energy Nuclear Physics. Spring term. Credit four hours. Three lectures. Prerequisite: an introductory course in atomic and nuclear physics, including quantum mechanics.

Low-energy nuclear physics as an organized body of experimental facts. Properties of ground and excited states of nuclei; models of nuclear structure; low-energy nuclear reactions and scattering, absorption, fission, resonance effects, coherent scattering effects. At a level between *Introductory Nuclear Physics* by Halliday, and *Nuclear Physics* by Fermi.

8312 Nuclear Reactor Theory I. Fall term. Credit four hours. Three lectures. Prerequisite: one year of advanced calculus and an introductory course in atomic and nuclear physics.

The physical processes in neutron chain reactors are described. The theory of neutron diffusion and slowing down is developed and applied to these processes. Neutron transport theory is introduced. At the level of *Nuclear Reactor Theory* by LaMarsh.

8313 Nuclear Reactor Theory II. Spring term. Credit three hours. Three lectures. Continuation of 8312, primarily intended for students planning to do research in the fields of reactor physics and reactor engineering.

Delayed neutron kinetics, fission product poisoning, nonlinear kinetics, perturbation theory, theory and measurement of neutron importance, temperature coefficients, control rod theory, hydrogenous reactors, neutron transport and heterogeneous reactor theory. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner.

8314 Neutron Transport Theory. Spring term. Credit three hours. Prerequisite: 8312 or consent of the instructor.

The linear Boltzmann equation describing neutron migration in matter is intensively studied. Topics will vary, but may include Milne's problem, neutron thermalization, deep penetration of radiation, as well as a formal development of approximate methods of solution. At the level of *Neutron Transport Theory* by Davison.

8333 Nuclear Reactor Engineering. Fall term. Credit four hours. Three lectures. Prerequisite: consent of the instructor.

A selected set of topics representing the fundamentals of nuclear reactor engineering; energy conversion and power plant thermodynamics, fluid flow and heat transfer, thermal stresses, radiation protection and shielding, materials for nuclear reactors, economics of nuclear power and fuel cycles, instrumentation and control. At the level of *Nuclear Reactor Engineering* by Glasstone and Sesonske.

8334 Nuclear Engineering Seminar. Spring term. Credit four hours. Prerequisite: 8333.

A conceptual design study of a nuclear reactor system. Emphasis on the interplay of requirements of safety and economics in the design of nuclear power systems.

8351 Nuclear Measurements Laboratory. Spring term. Credit four hours. Two afternoon periods of 2½ hours each. Prerequisite: some knowledge of nuclear physics.

Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Some twenty different experiments are available in the areas of nuclear and reactor physics. Among these are experiments on emission and absorption of radiation; on radiation detectors and nuclear electronic circuits; on interactions of neutrons with matter (absorption, scattering, moderation, and diffusion); on activation analysis and radiochemistry; and on properties of a subcritical assembly. Many of the experiments use the TRIGA reactor. The student is expected to perform eight to ten experiments, selected to meet his needs.

8352 Advanced Nuclear and Reactor Laboratory. Either term. Credit three hours. Two afternoon periods of 2½ hours each. Prerequisite: 8309 and 8351 or 8312.

Laboratory experiments plus informal lectures on experimental methods in nuclear physics and reactor physics. Some ten different experiments are available, among them one using the Cornell Critical Facility.

Materials Science 6873 Materials Science for Engineers. Fall term. Credit three hours. Three lectures.

Structure of crystals. Crystal lattice properties. Crystal defects (point, line, planar). Thermodynamics of solids. Diffusion and kinetics (emphasis on defect annealing, e.g., polygonization, recrystallization, grain growth, point defect recovery, etc.). Mechanical properties (role of crystal defects in plastic deformation, creep, fracture). Topics in radiation damage including defect productions, radiation damage annealing and effect of damage on physical properties.

Operations Research

Faculty
Robert E. Bechhofer, Louis J. Billera, Mark Brown, Richard W. Conway, Stella C. Dafermos, Mark J. Eisner, Hamilton Emmons, Henry P. Goode, Jack C. Kiefer, William F. Lucas, Walter R. Lynn, William L. Maxwell, Howard L. Morgan, George L. Nemhauser, Narahari U. Prabhu, Sidney Saltzman, Byron W. Saunders, Andrew Schultz, Jr., Shaler Stidham, Jr., Howard M. Taylor 3d, Lionel I. Weiss

Field Representative
William L. Maxwell, 366 Upson Hall

MAJOR AND MINOR SUBJECTS
Applied Probability and Statistics
Industrial Engineering
Information Processing (major for M.S. only)
Operations Research
Systems Analysis and Design

ADMISSION REQUIREMENTS. A prospective M.S. or Ph.D. candidate with a major in the Field must hold a Bachelor's degree in engineering, mathematics, economics, or the physical sciences from an institution of recognized standing. In addition, he must have a commendable undergraduate scholastic record and must supply other evidence of his interest in, and ability to pursue, advanced study and research in his major and minor subjects. Submission of the results of the Graduate Record Examination is strongly recommended for all applicants and is essential for fellowship and assistantship applicants.

Further information, including a brochure entitled *Operations Research at Cornell*, may be obtained by writing to the office of the Field Representative.

APPROPRIATE MINOR SUBJECTS. The following minor subjects have been chosen most frequently in recent years: computer science, econometrics, environmental systems engineering, managerial economics, mathematics, regional planning, and water resources. These subjects are described elsewhere in this *Announcement* or the *Announcement of the Graduate School: Social Sciences*.

LANGUAGE REQUIREMENTS. A student in a Ph.D. program must demonstrate reading ability in one foreign language, chosen from French, German, Russian, or others to be approved by petition to the Field. There is no language requirement for the M.S. degree.

PH.D. EXAMINATIONS. In addition to the admission to candidacy examination, ordinarily taken during the third year of graduate study, and the final examination on the thesis, the Field requires a qualifying examination, normally taken during the second term of graduate study. This examination will serve to determine the ability of the candidate to pursue doctoral studies, and to assist the Special Committee in developing his program of study.

Opportunities for Study and Research

APPLIED PROBABILITY AND STATISTICS. This subject of study and research is designed for students primarily interested in the techniques and underlying theory of probability and statistics, particularly as applied to science and engineering problems. The techniques emphasized are those associated with applied stochastic processes (for example, queuing theory, traffic theory, inventory theory, and time-series analysis) and statistics (including statistical decision theory; the statistical aspects of the design, analysis, and interpretation of experiments, and of ranking and selection theory; reliability theory; statistical quality control; sampling inspection; and acceptance sampling).

Because a doctoral dissertation must represent a fundamental contribution to theory and application, students who elect work in this area are expected to acquire considerable knowledge of the theory of probability and statistics and majors are required to minor in mathematics.

INDUSTRIAL ENGINEERING. The analysis and design of the complex operational systems that occur in industry, particularly in manufacturing, are studied in this subject. Plant design, cost analysis and control, and production planning represent some of the major topics. A student is expected to have considerable facility in the modern analytical techniques associated with rational decision making and with the establishment of valid design criteria. These techniques are drawn from among inventory theory, queuing theory, mathematical programming, quality control, and computer simulation.

Because the design and operation of modern engineering systems applies to areas other than manufacturing, the use of the word *industrial* should not be considered restrictive. Industrial engineers frequently are employed as systems specialists in commerce, banking, distribution, merchandising, and hospital management.

INFORMATION PROCESSING. Analysis and design of systems which record, transmit, store, and process information are dealt with, emphasizing application and integration of equipment rather than the design of machines. Areas of interest include systems for information retrieval, manufacturing control, and traffic control. This subject also includes such underlying theoretical topics as information theory and computing language structure. The principal campus computing facility is an IBM 360/65, with on-line operation from many campus locations. A satellite 360/20 directly connected to the 360/65 is located in Upson Hall, where the Department of Operations Research is housed. Teletypewriter terminals are also in use.

OPERATIONS RESEARCH. The problem areas and techniques of operations research are approached from a highly analytical viewpoint. Emphasis is placed on constructing appropriate mathematical models to represent various real-life operational systems, and on developing techniques for analyzing the performance of these models. In this way procedures with desirable properties for dealing with such systems are developed. Queuing, inventory, reliability, replacement, scheduling theories, and simulation are among the major techniques employed. Optimization techniques such as mathematical programming (linear, nonlinear, and probabilistic), combinatorics, and dynamic programming are also used extensively, as are the various techniques of the mathematical theory of games.

The student's program emphasizes the use of the mathematical, probabilistic, statistical, and computational sciences in developing techniques of operations research. However, his ultimate goal may range from making a fundamental contribution to the techniques of operations research to applying operations research to problems in diverse professional areas.

SYSTEMS ANALYSIS AND DESIGN. Although the solution of systems problems requires knowledge of underlying theory, the inherent practical limitations of the problem must be understood. Analysis of a system alone is insufficient; alternative solutions must be generated before selecting the one which can best be integrated with other elements of the systems. Modeling concepts are equally important but only when they can produce workable systems. Illustrations of the design of integrated systems can be found in industry, the environment, commerce, and government. A good example is the design of urban traffic control systems. Research may involve the developing of new methodology or the synthesizing of new combinations from what is already known. The goal is to improve the understanding of systems or develop new decision criteria for such systems.

Faculty Research Interests

Robert E. Bechhofer: engineering statistics, design of experiments, ranking and selection procedures.
Louis J. Billera: game theory, combinatorial analysis, graph theory.
Mark Brown: stochastic processes, time-series analysis.
Richard W. Conway: information-processing systems, computer science.
Stella C. Dafermos: systems analysis, network theory.
Mark J. Eisner: mathematical programming, game theory.
Hamilton Emmons: operations research, inventory theory.
Henry P. Goode: manufacturing engineering, industrial statistics, sampling inspection.
Jack C. Kiefer: statistical decision theory, optimum experimental design, sequential analysis.
William F. Lucas: game theory, combinatorial analysis, graph theory.
Walter R. Lynn: environmental systems.
William L. Maxwell: information-processing systems, production control, systems simulation.
Howard L. Morgan: management information systems, information processing.
George L. Nemhauser: mathematical programming, operations research.
Narahari U. Prabhu: stochastic processes, queuing theory, storage theory.
Sidney Saltzman: information-processing systems, operations research, econometrics.
Byron W. Saunders: facility design, materials handling, manufacturing design.
Andrew Schultz, Jr.: operations research, systems analysis.
Shaler Stidham, Jr.: queuing theory, transportation systems.
Howard M. Taylor 3d: applied probability.
Lionel I. Weiss: statistical decision theory, sequential analysis, nonparametric statistics.

During the academic year 1971–72 several members of the faculty will be engaged in sponsored research on contracts or grants which provide financial support and which offer opportunities for thesis research. The research areas include statistical research with engineering applications, multiple decision selection and ranking procedures, game theory, n-person cooperative games, traffic control in urban networks, convergence of stochastic integrals, applications of statistical control theory, asymptotic indistinguishability of distributions, development of Cornell University programming languages.

FINANCIAL AID. In addition to several University-wide and College of Engineering fellowships, the following fellowships are specifically designated for incoming candidates in the Field of Operations Research:

John McMullen Graduate Fellowship. $2,400, plus tuition and fees.

Procter and Gamble Fellowship. $2,000, plus tuition and fees. A $700 allowance is available if the recipient is married.

Sun Oil Fellowship. $2,475, plus tuition and fees if the recipient is single or married without children. A $450 allowance is available if the recipient is married and has children.

Dexter S. Kimball Fellowship of Aeronautical Laboratory. $2,500 or more, plus tuition and fees.

Professional Degree

The Master of Engineering (Industrial) program is designed for those primarily interested in becoming proficient in the practice of modern industrial engineering and consists of coordinated course work concentrated on advanced analytical and design techniques. Special emphasis is placed on applications. In addition, candidates work on projects which require identification, analysis, and design of feasible solutions to some loosely structured engineering problems.

An applicant must have a Bachelor's degree in an engineering field and a commendable undergraduate record. Should his undergraduate program provide adequate preparation (approximately equal to the required forty semester credit hours of the Cornell undergraduate field program in Industrial Engineering), requirements for this degree can usually be completed in one academic year.

Information and applications for this program may be obtained by writing to: Professor Byron W. Saunders, Director of the School of Industrial Engineering and Operations Research, Upson Hall.

Courses

9460 Introduction to Probability Theory with Engineering Applications. Fall term. Credit four hours. Three lecture-recitations, one computation period. Prerequisite: Math 294 or equivalent.

Definition of probability and basic rules of probability theory. Random variables, probability distributions, and expected values. Special distributions important in engineering work and relations among them; elementary limit theorems. Introduction to stochastic processes and Markov chains and their applications in the construction of mathematical models of operation, with emphasis on queuing and inventory models.

9470 Introduction to Statistical Theory with Engineering Applications. Spring term. Credit four hours. Three lecture-recitations, one computation period. Prerequisite: 9460.

The application of statistical theory to problems associated with the analysis of data and inference drawn therefrom. Principles of statistical inference: estimating the value of the unknown parameters of probability distributions, testing hypotheses concerning these parameters; elements of statistical decision theory. Introduction to correlation theory and curve fitting by least squares. Applications in regression, statistical control, and experimentation.

9481 Introduction to Computer Science (Computer Science 401). Either term. Credit four hours. Two lectures, one recitation-computation.

Principles and characteristics of information-processing equipment, programming languages, and applications. Topics are selected to illustrate a wide range of current and potential areas of application, with emphasis on the modern digital computer as a symbol-manipulating device rather than as an arithmetic calculator. Number systems, computer logic and organization, and characteristics of current equipment are covered along with various aspects of programming. Introductory concepts and problems associated with using computers in information-processing systems, real-time control systems, simulated experimentation, and the design process are also considered.

9501 Engineering Administration. Spring term. Credit three hours. Three lecture-recitation periods.

Organization of the engineering function, planning and analysis of engineering activities. Project management and control. Problems of innovation and introducing technological change. Measurement and evaluation of engineering activities. Selected topics from current literature.

9511 Industrial Systems Design. Spring term. Credit four hours. Two lectures, one recitation. Intended for advanced undergraduates and graduates seeking degrees in engineering.

A discussion of the problems of design and control of industrial systems. The development of design alternatives and their evaluation. Measures of system effectiveness and sensitivity. The role and place of information handling in systems control. Experimental procedures in testing system design with computer simulation. Term papers and design projects by individuals and groups will be expected.

9512 Statistical Methods in Quality and Reliability Control. Spring term. Credit three hours. Three lectures. Prerequisite: 9470 or equivalent.

Control concepts; control chart methods for attributes and for variables; process capability analysis; attributes acceptance-sampling plans and procedures; double- and multiple-sampling inspection; elementary plans and procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability application; life and reliability analysis of components; analysis of series and parallel systems; standby and redundancy; elementary sampling-inspection procedures used for life and reliability.

9513 Systems Engineering. Spring term. Credit three hours. Two recitations, one laboratory. Prerequisite: 9320 and 9370 or permission of the instructor.

Methods of describing, analyzing, and manipulating complex, interrelated open systems. Graphical and mathematical analysis. Techniques of design of transportation, service, and information systems and appropriate evaluation methods.

9521 Production Planning and Control. Spring term. Credit four hours. Three recitations, one computational period. Prerequisite: 9320 and 9321, or permission of the instructor.

Methods for the planning and control of large-scale operations with emphasis on manufacturing systems. Topics will include sales and production forecasting; manufacturing-planning; routing, scheduling, and loading; sequencing; dispatching; planning and control of inventories. Emphasis will be on mathematical and statistical methods for performing these functions, but empirical systems and procedures in common use will also be discussed and evaluated.

9522 Operations Research I. Fall term. Credit three hours. Three lecture-recitation periods. Prerequisite: permission of the instructor.

Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, nonlinear programming, dynamic programming, introduction to inventory theory; comprehensive problems and case studies.

9523 Operations Research II. Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9460 or permission of the instructor.

Models for inventory and production control; replacement theory; queuing, including standard birth- and death-process model and nonstandard models, application of queuing theory; simulation; game theory; illustrative examples and problems.

9524 Problems in Operations Research. Credit three hours. One two-hour meeting a week. Prerequisite: 9523 or equivalent.

An advanced seminar concentrating on problem definition, measures of effectiveness, applicability of various analytical methods to the solution of real problems.

9525 Flow and Scheduling in Networks. Spring term. Credit three hours. Three lecture-recitation periods.

Network analysis for continuous static flow; feasibility theorems, capacity determination, minimal cost operation. Sequencing models for deterministic discrete flow networks. Determination of capacity, routing, and discipline for networks of queues.

9526 Mathematical Models—Development and Application. Fall term. Credit four hours. Three lecture-recitations, one computation period. Prerequisite: 9320 and 9321, or equivalent.

Examination of relevant probabilistic and deterministic models in relation to industrial engineering work. The function of models and their usefulness in analysis, synthesis, and design. Emphasis will be given to the application of various models, their modification to fit special circumstances, and the development of new models to describe particular conditions or situations. Markov chains and dynamic programming will be discussed.

9527 Theory of Traffic Flow. Spring term. Credit three hours. Two lectures. Prerequisite: 9360 or permission of the instructor.

Study of various mathematical theories of traffic flow. Microscopic models (car following models). Macroscopic models (kinematic wave theory). Stochastic properties of traffic flow at low density. Probability models for traffic lights and optimal control of signalized intersections. Traffic flow on transportation networks. Application to traffic assignment. Traffic networks simulation system.

9529 Problems and Techniques in Optimization. Spring term. Credit three hours. Three lectures. Prerequisite: 9360 and 9320.

Selected topics in the application of operations research techniques to problems encountered in actual situations. Specific topics treated, generally related to mathematical programming, are at the discretion of the instructor. Typical subjects are column generation methods, network algorithms, techniques for handling uncertainty, computation of nonlinear programs, and enumeration methods for integer problems, as applied to scheduling, location, distribution and engineering design problems.

9530 Mathematical Programming I. Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: Math 331 and Math 441 or 9320 or permission of the instructor.

The geometry and duality of linear programming. Complete regularization and the resolution of degeneracy. Adjacent extreme-point methods such as the simplex, dual, and multipage in linear and nonlinear problems. Models of transportation and network type, and zero-sum and two-person games. Mixing routines and decomposition. Introduction to integer programming. Convex programming and Kuhn-Tucker theory.

9531 Mathematical Programming II. Fall term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9530.

Complementary pivot theory, semi-infinite programming and duality in convex programming. Computational algorithms. Integer programming. Chance-constrained programming and piecewise-linear decision rules. Combinatorial analysis and extremal methods.

9533 Combinatorial Analysis. Fall term. Credit three hours. Three lecture-recitation periods.

Incidence systems such as block designs, finite geometries, and other combinatorial designs, counting and enumeration techniques, combinatorial extremum problems, matroids, coding theory, selected topics in graph theory.

9534 Graph Theory. Spring term. Credit three hours. Three lecture-recitation periods.

Finite, infinite, directed, undirected, combinatorial, and topological graphs. Connectedness, planarity and imbedding problems, enumeration problems, coloring and matching problems, automorphism group of a graph, generalizations of graphs, matrix methods, network problems. Applications to electrical networks, economics, and sociometry.

9535 Game Theory. Fall term. Credit three hours. Three lecture-recitation periods. Prerequisite: permission of the instructor.

Two-person–zero-sum games; the minimax theorem, relationship to linear programming. Two-person–general-sum games. Noncooperative n-person games; Nash equilibrium points. Cooperative n-person games: the core, stable sets, Shapley value, bargaining set, kernel, nucleolus. Games without side payments. Games with infinite numbers of players. Economic market games.

9537 Dynamic Programming. Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9560.

Dynamic programming as a computational technique for solving a wide variety of problems. Concentration on deterministic problems; the knapsack problem, the obstacle course problem, finite horizon inventory models with known demand. Introduction to Markov sequential decision problems; Howard's algorithm in the finite state and action space case.

9538 Game Theory Seminar. Spring term. Credit three hours. Prerequisite: 9535 or permission of the instructor.

A seminar in which students read and report on current papers of interest in game theory, primarily in the area of n-person cooperative theory.

9539 Selected Topics in Mathematical Programming. Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9530 and 9531.

Current research topics such as integer programming over finitely generated groups, chance-constrained games, duality theory, infinite games.

9550 Engineering Economic Analysis. Fall term. Credit three hours. Three lectures.

Use of cost information for financial reporting, cost control, and decision making. Theory of double-entry accrual accounting. Use of costs in manufacturing: job order versus process costing; predetermined overhead rates, standard costs and variances. Modification of cost information for decision making: cost dichotomies, profit-volume charts, direct costing, costing of joint products and by-products, economic lot sizes, use of costs in other models of operations research. Capital investment planning: the time value of money, use of interest rates, ranking procedures for proposed projects, handling of risk and uncertainty.

9551 Advanced Engineering Economic Analysis. Spring term. Credit four hours. Three lectures. Prerequisite: 9311 or equivalent.

Topics include: capital investment planning procedures, project ranking, interdependence of productive investment and financing decisions. Applications of linear programming to capital budgeting problems. Theory of the firm including objectives, market structure, and pricing policies. Problems of profit measurement in the decentralized firm, including transfer pricing.

9560 Applied Stochastic Processes. Spring term. Credit four hours. Three lectures, one recitation. Prerequisite: a course in probability such as 9460 or Math 371; or 9160 and 9321.

An introduction to stochastic processes emphasizing a variety of applications of the basic theory. Some of the following topics are covered: second order processes; Markov chains and processes; diffusion processes, renewal theory and recurrent events; fluctuation theory; random walks; branching processes; Brownian motion; birth and death processes. Examples are drawn from queuing theory, population growth and other ecological models, and inventory theory.

9561 Queuing Theory. Fall term. Credit three hours. Two recitations, one computation period. Prerequisite: 9460 and permission of the instructor.

Definition of a queuing process. Poisson and Erlang queues. Imbedded chains. Transient behavior of the systems M/G/1 and GI/M/1. The general queue GI/G/1. Bulk queues. Applications to specific engineering problems such as shop scheduling, equipment maintenance, and inventory control.

9562 Inventory Theory. Spring term. Credit three hours. Three lecture-recitation periods. Prerequisite: 9460 and permission of the instructor.

An introduction to the mathematical theory of inventory and production control with emphasis on the construction and solution of mathematical models; topics drawn from recent technical literature will include deterministic and stochastic demands; dynamic programming and stationary analyses of inventory problems; renewal theory applied to inventory problems; multiechelon problems; statistical problems; and production smoothing.

9565 Time Series Analysis. Spring term. Credit three hours. Three lectures. Prerequisite: permission of the instructor.

The Hilbert space projection theorem and its application to linear prediction and linear statistical inference. Spectral representations of wide sense stationary processes. Estimation of spectral densities and other topics in empirical spectral analysis. Discussion of several time series models, and of the basic statistical techniques associated with the models.

9569 Selected Topics in Applied Probability. Either term. Credit three hours. Three lectures. Prerequisite: 9560 and permission of the instructor.

Selected topics in applied probability for advanced students. Topics will be selected from the current literature and the research areas of the staff.

9570 Intermediate Engineering Statistics. Fall term. Credit three hours. Two lectures, one computation period. Prerequisite: 9370 or 9470, or permission of the instructor.

Application of statistical methods to the efficient design, analysis, and interpretation of engineering experiments; rational choice of sample size for various statistical decision procedures, and the operating characteristic curves of these procedures; curve fitting by least squares; simple, partial, and multiple correlation.

9571 Design of Experiments. Fall term. Credit four hours. Two lectures, one computation period. Prerequisite: 9470 or permission of the instructor.

Use and analysis of experimental designs such as randomized blocks, Latin squares, and incomplete blocks; analysis of variance and covariance; factorial experiments, confounding, fractional replication; statistical problems associated with finding best operating conditions; response surface analysis.

9572 Statistical Decision Theory. Fall term. Credit three hours. Three lectures. Prerequisite: 9470 or equivalent.

The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules. Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function, and other nonparametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement.

9573 Statistical Multiple-Decision Procedures. Spring term. Credit three hours. Two recitations, one computation period. Prerequisite: 9571 or permission of the instructor.

The study of multiple-decision problems in which a choice must be made among two or more courses of action. Statistical formulations of the problems. Fixed-sample size, two-stage, and sequential procedures. Special emphasis on applications to ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Recent developments.

9574 Nonparametric Statistical Analysis. Fall term. Credit three hours. Three lectures. Prerequisite: 9470 or permission of the instructor.

Estimation of quantiles, cumulative distribution functions, and probability density functions. Properties of order statistics, and rank order statistics. Hypothesis testing in one and two sample situations. Large sample properties of tests and asymptotic distributions of various test statistics.

9579 Selected Topics in Statistics. Either term. Credit three hours. Two recitations, one computation period. Prerequisite: 9470 or permission of the instructor. Offered as required.

Selected topics chosen from such areas as nonparametric statistical methods, sequential analysis, multivariate analysis.

9580 Digital Systems Simulation. Fall term. Credit four hours. Two lectures, one recitation. Prerequisite: 9481 and 9470, or permission of the instructor.

The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program, synchronization and file maintenance, random number generation, random deviate sampling. Programming in simulation languages. Problems in the design of effective investigations using simulation, and statistical considerations when sampling from a simulated process. Applications of simulation.

9582 Data Processing Systems. Fall term. Credit three hours. One lecture, one computation period. Prerequisite: 9481 or permission of the instructor.

The design of integrated data processing systems for operational and financial control; questions of system organization, languages, and equipment appropriate to this type of application; file structures, addressing and search problems, sorting techniques; problems of multiple-remote-input, on-line data processing systems; techniques of system requirement analysis.

9589 Selected Topics in Information Processing. Either term. Credit four hours. Two recitations, one laboratory. Prerequisite: 9481 and permission of the instructor.

Selected topics in the design of computer systems to implement operations research techniques.

9591 Operations Research Graduate Seminar. Both terms. Credit one hour. One weekly 1½-hour meeting.

Devoted to presentation, discussion, and study of research in the Field. Distinguished visitors from other universities and institutions, both domestic and foreign, as well as faculty members and advanced graduate students of the Department and the University speak on topics of current interest.

Physics

Faculty
Vinay Ambegaokar, Neil W. Ashcroft, Karl Berkelman, Hans A. Bethe, Raymond Bowers, Andrew A. Browman, Peter A. Carruthers, David G. Cassel, Geoffrey V. Chester, Robert M. Cotts, John W. DeWire, Michael E. Fisher, Douglas B. Fitchen, Bernard Gittelman, Kurt Gottfried, Kenneth I. Greisen, Louis N. Hand, Donald L. Hartill, Paul L. Hartman, Donald F. Holcomb, Toichiro Kinoshita, James A. Krumhansl, David M. Lee, Raphael M. Littauer, Eugene C. Loh, Herbert Mahr, Bruce W. Maxfield, Boyce D. McDaniel, N. David Mermin, Nariman B. Mistry, Herbert F. Newhall, Jay Orear, Lyman G. Parratt, John Peoples, Robert O. Pohl, John D. Reppy, Robert C. Richardson, Edwin E. Salpeter, Albert J. Sievers, Robert H. Silsbee, Albert Silverman, Peter C. Stein, Richard M. Talman, D. Hywel White, John W. Wilkins, Kenneth G. Wilson, Robert R. Wilson, William M. Woodard, Tung-Mow Yan, Donald R. Yennie

Also on the faculty, but rarely serving on graduate students' Special Committees, are typically four visiting professors and about forty Ph.D. instructors and research associates.

Members of related fields who teach graduate level courses in Physics or serve as thesis advisers to Physics graduate students: Boris W. Batterman, Trevor R. Cuykendall, Mark S. Nelkin, Thor N. Rhodin, John Silcox, Watt W. Webb.

Field Representative
Robert H. Silsbee, 113 Clark Hall

MAJOR AND MINOR SUBJECTS
Physics
Experimental Physics
Theoretical Physics

The major or minor subject may be *physics* only if accompanied by a minor or major subject, respectively, outside the Field of Physics. The major subject may be *experimental physics* only if accompanied by *theoretical physics* as a minor, and may be *theoretical physics* only if accompanied by *experimental physics* as a minor.

For either the M.S. or Ph.D. degree in the Field of Physics it suffices to have one minor subject, either inside or outside the Field. For the Ph.D. degree, however, the student's Special Committee may require two minors. If two minors are required, at least one must be outside the Field.

Each student has a Special Committee that (a) represents his major and minor interests and (b) serves as an advisory and examining committee. This Special Committee consists of at least three members with at least two from the Field of Physics. The initial committee is normally appointed, but the student himself is expected to choose his permanent committee (to replace the appointed committee) as soon as his major and minor interests become reasonably firm. The chairman of the permanent committee represents the major subject and normally, but not necessarily, supervises the thesis.

AIMS AND OPERATIONS OF THE FIELD. The graduate level physics program at Cornell is designed to give the student adequate background in the advanced concepts and techniques of both theoretical and experimental physics to prepare him for a career at the most advanced level in research or teaching. Although the program focuses on the Ph.D. degree in Physics, there is a wide variety of options available to the student during his work at Cornell, both in final level of achievement and in the area of special concentration.

ADMISSION. The large majority of entering students have completed an undergraduate physics major program including such junior-senior courses as analytical mechanics, electricity and magnetism, optics and wave motion, electronics, atom physics, thermodynamics, quantum mechanics, and solid state and nuclear physics; some junior-senior-course laboratory work in physics is also expected. Knowledge of differential equations and of vector calculus is essential.

In the selection of new students, emphasis is on the quality of the undergraduate work and on the promise for graduate work rather than on the extent of undergraduate study in physics and related subjects. Many entering students enroll in one or more undergraduate courses to make up deficiencies.

Almost all students are admitted directly into the Ph.D. program. If an applicant's academic background in physics is either deficient or questionable, he may be admitted *provisionally* into the Ph.D. program; this is fairly common for students from foreign countries. Some students are admitted directly as Master's candidates either for the M.S. or for the professional M.S.T. degree*. Some students in the Ph.D. program prefer to work toward the M.S. degree either as a terminal degree or on the way toward a Ph.D. degree. Most students, however, prefer to proceed directly for the Ph.D. degree.

A student who wishes to interrupt his graduate work with a leave of absence for longer than one year must apply for readmission on the same basis as a new student, i.e., he must obtain the recommendation of the Field Committee on Admissions.

MASTER'S (M.S.) DEGREE WITHOUT A THESIS. It is permissible in the Field of Physics to replace the normally required Master's thesis with additional courses in physics. If a student in the Ph.D. program has passed two years of graduate physics courses and then passes the admission to Ph.D. candidacy examination "at the Master's level," he may be recommended for the M.S. degree without a thesis and without further examination.

LANGUAGE REQUIREMENT. No foreign language is required for either a Master's or a Ph.D. degree. However, proficiency in at least one foreign language (preferably Russian, German, or French) is very desirable; it is strongly recommended that this proficiency be acquired before graduate work is undertaken.

EXAMINATION REQUIREMENTS. For an M.S. degree: either the master's final examination or the admission to Ph.D. candidacy examination is required.

For a Ph.D. degree: (a) the qualifying examination (required specifically by the Field of Physics), taken normally at the beginning of the second year of graduate work and consisting of a written part administered in September just before the start of classes and an oral part to be taken within the first month of the fall term; (b) the comprehensive admission to Ph.D. candidacy examination, usually taken after the second year of graduate work, consisting of written and oral parts; (c) the Ph.D. final examination, an oral examination confined to the subject of the thesis.

FINANCIAL AID. Essentially all first- and second-year graduate physics students hold either a teaching appointment, a fellowship, or both (see below). The faculty emphasizes the training importance of teaching experience and encourages *all* students to teach at least one year and preferably two years. Regular teaching appointments, typically in undergraduate classrooms and laboratories or as readers, involve a total of fifteen to twenty hours per week. Any fellowship holder who wishes it, and whose fellowship conditions allow it, may have a teaching appointment, usually with reduced duties and with a reduced (additional) stipend.

Most third- and higher-year students are either fellows, research assistants, or both. Regular research appointments involve nominally twenty hours per week of work closely allied to the student's doctoral thesis, which is normally undertaken at the beginning of the third year of graduate work. Holding a teaching or a research appointment does not significantly delay the completion of the requirements for an advanced degree.

Most assistantships and fellowships are for the academic year. Very few assistantships are available for first- or second-year students during the summers, although almost all higher-year students hold two-month summer research assistantships. Many fellowships are for twelve months (rather than nine) or may be extended to twelve; the twelve-month tenure is of course recommended.

FURTHER INFORMATION. A copy of the brochure *Graduate Study in Physics at Cornell* (containing additional information for the prospective graduate student), a reference list of publications from the Department of Physics for the preceding year, and a copy of application materials for an assistantship in physics, may be obtained by writing to: Chairman of the Department of Physics, Clark Hall.

Research Opportunities

THEORETICAL PHYSICS. Many-body theory, theory of superconductors, theory of metallic state, superfluidity, statistical mechanics and irreversibility, phonon physics and transport processes, low-temperature physics, electrodynamic phenomena and defects in solids, plasma physics, dispersion relations and strong interactions (high-energy limits, "bootstrap" dynamics, models of reaction processes), internal symmetries and their connection with strong interaction dynamics, current algebra, quantum electrodynamics, quantum field theory and renormalization, astrophysics, and stellar structure. About half of the theory group is primarily associated with the Laboratory of Nuclear Studies and about half primarily with the Laboratory of Atomic and Solid State Physics; however, continual interaction takes place both within the entire group of theorists and with all the experimentalists.

* See p. 26. For information about the objectives and requirements of the M.S.T. degree with a concentration in physics, write directly to Professor Kenneth I. Greisen, Department of Physics, 111 Clark Hall.

EXPERIMENTAL HIGH-ENERGY NUCLEAR RESEARCH. Photoproduction processes involving intermediate-mass mesons and hyperons, energy levels of excited states of the proton, detailed study of the structure of the proton, synchrotron radiation, gamma ray interactions with matter, Compton scattering, photodisintegration of nuclei, cosmic rays including air showers and methods of detection of neutral primary radiations, properties of elementary particles, and high-energy interactions. Large machine shop and electronics shop; 10-Gev electron-synchrotron. Cornell staff and students also participate in research with the AGS 30-Gev proton-synchrotron at Brookhaven.

EXPERIMENTAL ATOMIC AND SOLID STATE PHYSICS. Phonon physics, superconductivity, optical spectroscopy, low-temperature physics, magneto-plasma waves, spin resonance, x-ray emission and absorption spectra, electron diffraction, thermal conductivity, and spin relaxation. Large machine shop and glass-blowing shop; several large stable DC magnets, superconducting solenoids, vacuum UV spectrographs, IR to UV monochromators, spin resonance spectrometers, and x-ray spectrometers. Available through association with the Materials Science Center of Cornell University are: central facilities for electronics, crystal growing, cryogenics (a millidegree facility), analytical chemistry, technical operations, high pressure, x-ray and metallography, crystal irradiation and electron microscopy.

RELATED FIELDS. In addition to the specific areas of research listed above, physics students often work on thesis projects with faculty members in closely related Fields such as Astronomy and Space Sciences, Applied Physics, Theoretical and Applied Mechanics, Materials Science and Engineering, Chemistry, etc. For some indication of physics-related research projects and facilities in those fields, see the appropriate sections of this catalog. Even though the student chooses to work within the Field of Physics, the cross-stimulation provided by the seminars and research facilities in those related areas is extremely valuable.

Courses

Graduate physics courses are numbered 500 or higher; they are listed below but are preceded by a few popular undergraduate senior courses. Other courses at the undergraduate level are listed in the *Announcement of the College of Arts and Sciences.*

Most first-year graduate physics students take three courses each term; occasionally, but not normally, a student who does not hold a teaching or research appointment takes four courses. Students are encouraged to complete their "core" courses—those to be taken before the Master's final or the admission to Ph.D. candidacy examination—within one calendar year for the Master's and within two calendar years for the Ph.D.

In order to introduce more flexibility in planning a program of studies, Physics 510 and 574 are also taught during the summer session. Physics 510 may be taken during the summer before the first academic year, and either course the following summer.

A typical first-year program for a Ph.D. or M.S. student having adequate preparation, a program without much leeway, follows.

First term: Physics 510 and 561; Math 415.

Second term: Physics 562 and 572; Math 416 or M.S. thesis.

Supplementing the formal courses, students and staff meet over coffee or tea at weekly physics colloquia and topical seminars. For first-year graduate students a special seminar is held biweekly to acquaint the newcomers with Cornell and the Department of Physics. Every graduate student is allotted a study desk in one of the physics buildings. He is encouraged to assume the full life of the community of active physicists as soon as possible.

431–432 Introductory Theoretical Physics I and II. Throughout the year. Credit four hours a term. Prerequisite: (a) 207–208 or the equivalent for 431, either 431 or 303 and 322 or the equivalent for 432, and (b) coregistration in Math 421–422, or consent of the instructor. Primarily for graduate students in a science other than physics (e.g., chemistry, engineering, or biology). Fall term: Mr. Feigenbaum. Spring term: Mr. Roy.

Fall term. Mechanics, including Newtonian mechanics, Lagrange's and Hamilton's equations, central forces, rigid body motion and small oscillations. At the level of *Mechanics* (2nd ed.) by Symon.

Spring term. Electricity and magnetism, including electrostatics, magnetostatics, boundary-value problems, dielectric and magnetic media, circuit theory, Maxwell's equations and propagation of electromagnetic waves. At the level of *The Physics of Electricity and Magnetism* by Scott.

443 Atomics and Introductory Quantum Mechanics. Fall term. Credit four hours. Prerequisite: 305, 319, and 325, or 432, and Math 316 or 421, or consent of the instructor. Mr. Bowers.

Difficulties with the classical interpretations of atomic properties are resolved in terms of quantum mechanics. At the level of *Introduction to Quantum Theory* by Park.

444 Nuclear and High-Energy Particle Physics. Spring term. Credit four hours. Prerequisite: 443 or consent of the instructor. Mr. Browman.

Behavior of high-energy particles and

radiation; elementary particles; basic properties of nuclei; nuclear reactions; nuclear forces; cosmic rays; general symmetries and conservation laws of nature. At the level of *Nuclei and Particles* by Segre.

454 Introductory Solid State Physics. Spring term. Credit four hours. Prerequisite: 443 or Chemistry 593, or consent of the instructor. Mr. Mahr.

A semiquantitative introduction to modern solid state physics, including lattice structure, lattice vibrations, thermal properties, electron theory of metals and semiconductors, magnetic properties, and superconductivity. At the level of *Introduction to Solid State Physics,* third edition, by Kittel.

500 Informal Graduate Laboratory. Either term. (Also offered during the summer.) Credit one to three hours a term. Associated with the Physics 510 laboratory. Primarily for students who have had at least the equivalent of 310 or 360 but who do not have the prerequisites for 510. Mr. Hartman and staff.

505–506 Design of Electronic Circuitry. Throughout the year. Credit two hours a term. Prerequisite: 360, Math 315, and familiarity with complex representation of a-c signals, or consent of the instructor; 505 is prerequisite to 506. Fall term: Mr. Peoples. Spring term. Mr. Maxfield.

Circuit techniques and design in electronic measurement and instrumentation with emphasis on pulse waveforms. At the level of *Pulse Electronics,* 1965, by Littauer.

510 Advanced Experimental Physics. Either term. (Also offered during the summer.) Credit three hours a term. Prerequisite: 410 and 443 or consent of the instructor. At least one term of 510 is ordinarily required of every graduate physics student during his first year. Mr. Hartman and staff.

About seventy different experiments are available among the subjects of mechanics, acoustics, optics, spectroscopy, electrical circuits, electronics and ionics, heat, x rays, crystal structure, solid state, cosmic rays, and nuclear physics. The student is expected to perform four to eight experiments selected to meet his individual needs. Stress is laid on independent work.

520 Projects in Experimental Physics. Either term. Credit three hours a term. Prerequisite: 510 and consent of the instructor. Hours to be arranged with individual faculty supervisor.

Projects of modern topical interest that involve some independent development work by the student. Opportunity for more initiative in experimental work than is possible in 510. One or two projects in different areas typically comprise a term's work (e.g., with the Cornell synchrotron, or with a liquid helium cryostat, or with both).

551 Formalism of Classical Mechanics. Fall term. Credit two hours. S-U grades only. Prerequisite: an elementary course in classical mechanics. Intended for students with little or no background in the Hamiltonian and Lagrangian formulations of classical mechanics. Mr. Krumhansl.

Lagrangian and Hamiltonian formulation of classical mechanics. At the level of *Mechanics,* by Landau and Lifshitz.

561 Classical Electrodynamics. Fall term. Credit three hours. Prerequisite: 325 or 432, and coregistration in Math 415 or 423, or consent of the instructor. Mr. Haymaker.

Maxwell's equations, electromagnetic potentials, electrodynamics of continuous media (selected topics), special relativity, and radiation theory. At the level of *Classical Electrodynamics* by Jackson.

562 Thermal, Statistical, and Continuum Physics. Spring term. Credit three hours. Prerequisite: 443 or coregistration in 572 and 319 or consent of the instructor. Mr. Nelkin.

Hydrodynamics, thermodynamics, and introductory statistical mechanics, including ensemble theory, Fermi-Dirac and Bose-Einstein statistics with applications. At the level of *Statistical Physics, Fluid Mechanics,* by Landau and Lifshitz.

572 Quantum Mechanics I. Either term. Credit three hours. Prerequisite: 443, and at least coregistration in 551 and Math 415 or 423, or consent of the instructor. Fall term: Mr. Wilson. Spring term: Mr. Bethe.

Dirac's formulation of quantum mechanics, transformation theory. Symmetries: angular momentum, the exclusion principle, time reversal. Elements of scattering theory and of perturbation theory. At the level of *Quantum Mechanics* by Gottfried. A familiarity with elementary aspects of the Schroedinger equation, including its application to simple systems such as the hydrogen atom, is assumed.

574 Quantum Mechanics II. Spring term. (Also offered during the summer.) Credit four hours. Prerequisite: 572 and at least coregistration in 562 and in Math 416, or consent of the instructor. Required of all Ph.D. majors in Theoretical Physics. Mr. Salpeter.

Discussion of various applications of quantum mechanics such as collision theory, theory of spectra of atoms and molecules, theory of solids, emission of radiation, and relativistic-quantum mechanics. At the level of *Quantum Mechanics of One- and Two-Electron Atoms* by Bethe and Salpeter.

612 Experimental Atomic and Solid State Physics. Spring term. Credit three hours. Prerequisite: 510, 561, and 562, or consent of the instructor. Mr. Fitchen.

Lectures on techniques and design principles, with emphasis on the study of solids by their interactions with electromagnetic fields. Topics include sources and detectors, scanning and resonance techniques, signal-processing, sample characterization, and environmental control.

614 Experimental High-Energy Physics. Spring term. Credit three hours. Prerequisite: 510, 561, and 562, or consent of the instructor. Two lectures and one problem discussion section per week. Mr. Hartill and staff.

Design principles of high-energy apparatus: accelerators, beam transport, detection systems, etc., with examples of their applications. Practice in the use of relativistic kinematics. Statistical analysis in the design and interpretation of experiments.

635 Solid State Physics I. Fall term. Credit three hours. Prerequisite: 572 and statistical physics at the level of 562, or consent of the instructor. Expected of every Ph.D. Experimental Physics major or minor. Mr. Fitchen.

An introduction to solid state physics including studies of lattice vibrations, the electronic structure of metals and insulators, with applications to electrical, thermal, and transport properties. At the level of *Principles of Theory of Solids,* 1964, by J. M. Ziman.

636 Solid State Physics II. Spring term. Credit three hours. Prerequisite: 635 or consent of the instructor. Mr. Silsbee.

The concepts developed in 635 are extended and applied to a survey of the following: band theory and the Fermi surface in metals, localized states, magnetism, neutron and light scattering, and phenomenological superconductivity.

645 Nuclear and Particle Physics. Fall term. Credit three hours. Prerequisite: 572 or consent of the instructor. Mr. Hand.

An introduction to the study of nuclear and particle physics, emphasizing the interaction between theory and experiment in developing the basic ideas. Topics to be covered include: general properties of nuclear matter, the two-nucleon system, beta decay, role of the pion in nuclear forces, classification of elementary particles, weak interactions of elementary particles. At the level of *Nuclear Interactions,* 1964, by De-Benedetti.

646 High-Energy Particle Physics. Spring term. Credit three hours. Prerequisite: 574 or 645 or consent of the instructor. Mr. Talman.

The physics of nucleons, mesons, and strange particles from an experimental point of view. High-energy phenomena, as opposed to classical nuclear physics, will be stressed. At the level of *An Introduction to Elementary Particles* by Williams.

NOTE: *In courses above 650 the final grades will be only S or U.*

651 Advanced Quantum Mechanics. Fall term. Credit three hours. Prerequisite: 574 or consent of the instructor. Mr. Kinoshita.

Relativistic quantum mechanics with emphasis on perturbation techniques. Extensive applications to quantum electrodynamics. Introduction to renormalization theory. At the level of *Relativistic Quantum Mechanics* by Bjorken and Drell.

652 Quantum Field Theory. Spring term. Credit three hours. Prerequisite: 651 or consent of the instructor. Mr. Yan.

Canonical field theory, model field theories, Green's functions, renormalization. Introduction to analytic properties of scattering amplitudes and dispersion relations. Applications to strong interactions. At the level of *Relativistic Quantum Fields* by Bjorken and Drell.

653 Statistical Physics. Fall term. Credit three hours. Prerequisite: 562 and 572, or consent of the instructor. Mr. Chester.

A survey of topics in contemporary statistical physics, such as the Boltzmann equation, plasmas, sound propagation, phenomenological Fermi liquid theory, critical phenomena of simple fluids and ferromagnets, classical fluids, introduction to Kubo formulae and Green's functions, and superfluids. At the level of *Statistical Physics* by Landau and Lifshitz.

654 Theory of Many-Particle Systems. Spring term. Credit three hours. Prerequisite: 635 and 653, or consent of the instructor. Mr. Wilkins.

The equilibrium and transport properties of microscopic systems of many particles are studied at zero and finite temperatures. Thermodynamic Green's function techniques are introduced and applied to such topics as normal and superconducting Fermi systems, superfluidity, magnetism, and insulating crystals.

657 Theory of Nuclei. Fall term. Credit three hours. Prerequisite: 574 and 645, or consent of the instructor. Offered in alternate years (offered in 1970–71) and only if registration exceeds nine students. Mr. Bethe.

661 High-Energy Phenomena. Fall term. Credit three hours. Prerequisite: 651 or consent of the instructor. Offered only if registration exceeds nine students. Mr. Carruthers.

Topics of current interest in the theory of strong interactions. At the level of *Dispersion Relations* by Klein.

665 Topics in Theoretical Astrophysics. Fall term. Credit three hours. Prerequisite: graduate student status with a good background in physics, or consent of the instructor. This course and Astronomy 560 alternate by year. Mr. Salpeter.

Typical topics are: theory of stellar structure, theory of stellar atmospheres, and theories of interstellar medium. Topics and their treatment will vary from year to year.

680 Special Topics. Either term. Credit one to three hours a term. Upon sufficient demand, seminars will be arranged in topics not covered in regular courses.

Typical topics are: group theory, analyticity in particle physics, weak interactions, superfluids, stellar evolution, plasma physics, cosmic rays, general relativity, low-temperature physics, x-ray spectroscopy or diffraction, and magnetic resonance.

690 Independent Study in Physics. Either term. Credit one to three hours a term. Special graduate study in some branch of physics, either theoretical or experimental, under the direction of any professional member of the staff. Permission of the staff member under whose direction the work is to be done *must be obtained before registration.*

Electrical Engineering 4661, Kinetic Equations (See p. 92.)

Statistics

Faculty
Robert E. Bechhofer, Isadore Blumen, Lawrence D. Brown, Mark Brown, Roger Farrell, Walter T. Federer, Ivor Francis, Harry Kesten, Jack Kiefer, Philip J. McCarthy, Narahari U. Prabhu, Douglas S. Robson, Shayle R. Searle, Daniel Solomon, Frank L. Spitzer, Howard M. Taylor 3rd, Lionel Weiss.

Field Representative
Isadore Blumen, 360 Ives Hall.

MAJOR SUBJECT
Statistics

MINOR SUBJECTS
Provisions for minoring in statistics are given in the descriptions of the Fields of Operations Research, Industrial and Labor Relations, Mathematics, and Plant Breeding and Biometry contained in the *Announcements* of the various areas of the Graduate School.

ADMISSION REQUIREMENTS. Since one of the principal aims of graduate work in the Field of Statistics is that of training individuals who will have a thorough knowledge of the theoretical basis of modern statistical method and will have demonstrated ability to make significant contributions to this theory, applicants should ordinarily have obtained nearly the equivalent of an undergraduate major in mathematics. It is strongly recommended that applicants resident in the United States during the year before entering the Graduate School present scores on the Graduate Record Examination Aptitude Test.

LANGUAGE REQUIREMENT. There is no foreign language requirement for the M.S. degree. A candidate for the Ph.D. degree must demonstrate reading ability in one language besides English, chosen from among French, German, or Russian.

PROGRAM OF STUDY. A student majoring in the Field of Statistics must complete a graduate sequence of courses in mathematical statistics which has been approved by his Special Committee. Other course work will be chosen from among the offerings of the members of the Field, as listed below. A doctoral student in the Field ordinarily has two minor subjects but may, in consultation with the chairman of his Special Committee, choose to work in one minor subject. One minor subject will often be in an area of interest to the student in which the methods of statistics find extensive application. A second minor is usually devoted to mathematics, computing, or a similar subject.

PH.D. EXAMINATIONS. In addition to the admission to candidacy examination, which will ordinarily be administered by the student's Special Committee during or at the end of the third year of graduate study, and the final examination on the thesis, the student will be given a qualifying examination. This examination will occur shortly after the first year of graduate study. It will serve to determine the ability of the candidate to pursue doctoral studies and to assist the Special Committee in developing a program of study for the candidate.

TEACHING AND RESEARCH INTERESTS OF THE FACULTY. In extremely broad terms, the teaching and research interests of faculty members are in the following general areas: biological applications of probability and statistics (Federer, Robson, Searle, Solomon); engineering and operations research applications of probability and statistics (Bechhofer, M. Brown, Prabhu, Taylor, Weiss); mathematical theory of probability and statistics (L. D. Brown, Farrell, Kesten, Kiefer, Spitzer); social science applications of probability and statistics (Blumen, Francis, McCarthy).

Some of the more specific areas of current interest are: analysis and probability theory (M. Brown, Kesten, Spitzer); design and analysis of experiments (Bechhofer, Federer, Kiefer, Robson, Searle); high-speed computing (Francis, Searle); mathematical theory of statistics (Farrell, Kiefer, Solomon); multiple decision procedures (Bechhofer); multivariate analysis (Blumen, Francis); nonparametric statistics (Blumen, Weiss); queuing and inventory theory (Prabhu); sampling theory (McCarthy, Robson); sequential sampling methods (Kiefer, Weiss); statistical control theory (Taylor); statistical genetics (Federer, Robson, Searle).

Courses

Descriptions of the following courses may be found in the *Announcements* of the various areas of the Graduate School under the Fields with which they are identified. In those sections reference is also made to several advanced seminars, both formal and informal, whose content varies from year to year.

Advanced Undergraduate and Master's Level Courses

OPERATIONS RESEARCH

9460 Introduction to Probability Theory with Engineering Applications.
9470 Introduction to Statistical Theory with Engineering Applications.
9512 Statistical Methods in Quality and Reliability Control.

9570 Intermediate Engineering Statistics.

INDUSTRIAL AND LABOR RELATIONS

310 Design of Sample Surveys.
311 Statistics II.
410 Techniques of Multivariate Analysis.
411 Statistical Analysis of Qualitative Data.

MATHEMATICS

371 Basic Probability.
472 Statistics.
473 Statistics.

PLANT BREEDING AND BIOMETRY

411 Stochastic Models in Biology.
417 Matrix Algebra in Biology and Statistics.
510 Statistical Methods I.
511 Statistical Methods II.

Advanced Master's and Doctor's Level Courses

OPERATIONS RESEARCH

9560 Applied Stochastic Processes.
9561 Queuing Theory.
9562 Inventory Theory.
9565 Time Series Analysis.
9571 Design of Experiments.
9572 Statistical Decision Theory.
9573 Statistical Multiple-Decision Procedures.

INDUSTRIAL AND LABOR RELATIONS

610 Economic and Social Statistics.
614 Theory of Sampling.

MATHEMATICS

571 Probability.
572 Probability.
574 Statistical Analysis.
575 Information Theory.
673 Analysis of Variance.
674 Design of Experiments.
675 Statistical Estimation.
676 Decision Functions.
677-678 Stochastic Processes.

PLANT BREEDING AND BIOMETRY

513 Design of Experiments I.
514 Design of Experiments II.
517 Linear Models.
518 Special Topics in Biometry.
519 Statistical Genetics.

Theoretical and Applied Mechanics

Faculty
Kyle T. Alfriend, Henry D. Block, Bruno A. Boley, Joseph A. Burns, Harry D. Conway, Edmund T. Cranch, Constantine Dafermos, Joseph C. Dunn, Herbert H. Johnson, Richard H. Lance, Geoffrey S. S. Ludford, John R. Moynihan, Yih-Hsing Pao, Richard H. Rand, David N. Robinson, Wolfgang Sachse

Field Representative
Yih-Hsing Pao, 237 Thurston Hall

MAJOR AND MINOR SUBJECTS
Fluid Mechanics
Mechanics of Materials
Solid Mechanics
Space Mechanics

The graduate program in mechanics emphasizes the learning of the fundamental principles of science and the understanding of the newest developments in engineering. Graduate students may pursue in depth studies in mechanics of particles, rigid and deformable solids, dynamics of liquids and gases, mechanical properties of materials and other related subjects in physics and mathematics. The analytical and experimental nature of the studies encourages thesis research that cuts across the boundaries of many fields. Current research topics include: (1) space mechanics—trajectories and orbits of space vehicles, stability and nonlinear oscillation of particles, celestial mechanics, and bionics and robots. (2) solid mechanics—wave propagation in solids, static and dynamic response of structures, elasticity, plasticity and continuum mechanics. (3) mechanics of materials—failure and fracture of solids, static and dynamic properties of composite materials. (4) fluid mechanics—non-Newtonian fluids, compressible fluid and magnetogasdynamics.

A student may elect to major in any one of the four subjects in the Field and must choose to minor in one subject of another Field. The most frequently selected minor Fields are Aerospace Engineering, Applied Mathematics or Mathematics, Applied Physics or Physics, Civil Engineering, Electrical Engineering, Materials Science and Engineering, Mechanical Engineering, and Operations Research. For major students, the Field maintains a general guideline on course work which is subject to the approval of a student's Special Committee. The Field Representative serves as the chairman of a student's Special Committee during his first term of residence.

ADMISSION. The Field admits students with backgrounds in physics, mathematics and any branch of engineering, and imposes no additional entrance qualifications beyond those of the Graduate School. Students who apply for fellowships or other financial aid are encouraged to submit Graduate Record Examinations scores.

EXAMINATIONS. In addition to the examinations required by the Graduate School, students enrolled in the Ph.D. program must take a qualifying examination administered by the entire faculty of the Field at the end of the first semester in residence.

OTHER FIELD REQUIREMENTS FOR DOCTORAL CANDIDATES. Each doctoral candidate must demonstrate reading ability in one language other than his native language. The language selected must be approved by his Special Committee; examination policy for proficiency in the language is set by the Field.

The Field regards teaching experience as an essential part of the academic training for all doctoral candidates and hence makes such experience a requirement for the degree.

FINANCIAL AID. In addition to University fellowships, teaching assistantships and a limited number of research assistantships are available in the Department of Theoretical and Applied Mechanics. Applications for assistantships are considered along with the admission to the Field and it is not necessary to submit a separate form to the Department.

Courses

Engineering Mathematics

1126–1127 Mathematical Concepts in Science and Technology. Fall and spring terms. Credit three hours a term. Prerequisite: one year of mathematical methods at or beyond the level of 1150–1151. Evening examinations. Mr. Dunn.

Primarily for students of engineering and the physical sciences. Intended to encourage study of modern abstract mathematics and its relationship to science and technology. Considers various applied problems and methods from the standpoint of underlying abstract mathematical similarity and follows with an introductory treatment of unifying concepts from modern analysis and algebra. Topics will include: the real-complex embedding and its significance for the theory of power series, linear differential equations, and operational (transform) calculus; the theory of contraction mappings on metric spaces and its relation to various iterative solution techniques and existence-uniqueness questions; spectral theory of symmetric linear operators on Hilbert spaces and its connections with matrix diagonalization and boundary value problems; the theory of constrained minimization of functionals on a Banach space and its relation to optimal control and programming problems. Physical motivation will be drawn from a variety of sources, historical and current, including the literature of theoretical mechanics, communication and control theory, and numerical analysis.

1180 Methods of Applied Mathematics I. Fall term. Credit three hours. Mr. Burns.

Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; functions of several real variables; vector fields and integral theorems; matrices; partial differential equations. The course emphasizes applications and techniques of solutions, wherever possible, and is intended for students who plan to use applied mathematics frequently. At the level of *Mathematics of Physics and Modern Engineering* by Sokolnikoff and Redheffer.

1181 Methods of Applied Mathematics II. Spring term. Credit three hours. Prerequisite: 1180 or equivalent. Mr. Burns.

Continuation of partial differential equations; Green's function; Fourier and Laplace transforms; complex variables; calculus of variations; tensor analysis.

1182 Methods of Applied Mathematics III. Fall term. Credit three hours. Prerequisite: 1181 or equivalent. Mr. Ludford.

Application of advanced mathematical techniques to engineering problems. Conformal mapping; complex integral calculus; Green's function; integral transforms; asymptotics including steepest descent and stationary phase; Wiener-Hopf technique; general theory of characteristics; perturbation methods; singular perturbations including PLK method and boundary layers. Development will be in terms of problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, electromagnetics.

1183 Methods of Applied Mathematics IV. Spring term. Credit three hours. Prerequisite: 1182. Mr. Ludford.

More extensive treatment of 1182 in same spirit. Topics include: method of matched asymptotic expansions. W.K.B. approximation; Hilbert-Schmidt and Fredholm theories of integral equations; singular integral equations. Wiener-Hopf equations with application to finite interval. Carleman equation and its generalization, effective approximations; further methods in partial differential equations, slot problems.

1184 Numerical Methods in Engineering. Spring term. Credit three hours. Prerequisite: 1181 or equivalent. Mr. Block.

Methods for obtaining numerical solutions to problems arising in engineering. Linear and nonlinear mechanical systems. Ordinary and partial differential equations, initial value problems, boundary value problems, eigenvalue problems and extrema. Calculus of variations. Function-space methods. Applications to vibrations, diffusion, heat transfer, wave propagation, membranes, plates, fluid flow, and celestial mechanics. Simulation of dynamical systems. Analog computation.

Mechanics of Solids

1263 Applied Elasticity. Fall term. Credit three hours. Mr. Conway.

Analysis of thin curved bars. Plane stress and plane strain in the circular cylinder, effects of pressure, rotation, and thermal stress. Small and large deflection theory of plates, classical and approximate methods. Strain energy methods. Symmetrically loaded thin cylindrical shell. Torsion of thin-walled members. A first course in the mechanics of elastic deformable bodies with structural applications.

1264 Theory of Elasticity. Spring term. Credit three hours.

General analysis of stress and strain. Plane stress and strain. Airy's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Mitchell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space.

1265 Mathematical Theory of Elasticity. Spring term. Credit three hours. Offered in alternate years. Mr. Dafermos.

Development in tensor form of the basic equations of large deformation elasticity; solution of certain large deformation problems. Linearization to infinitesimal elasticity. Boussinesq-Papkovich potentials and their application to three-dimensional problems; contact problems; plane stress by method of Muskhelishvili; application of conformal mapping; Cauchy integral techniques in elasticity, torsion problems.

1267 Introduction to the Inelastic Behavior of Solids and Structures. Fall term. Credit three hours. Offered in alternate years.

Introduction to the physical aspects of inelastic material behavior. Idealized models for microscopic analysis of elastic, plastic, viscous, viscoplastic and locking materials. Mathematical formulations and methods of solution. Design concepts.

1268 Theory of Plasticity. Spring term. Credit three hours. Offered in alternate years. Mr. Robinson.

Theory of inelastic behavior of materials. Plastic stress-strain laws, yield criteria, and flow laws. Flexure and torsion of bars, thick-walled cylinders, metal forming and extrusion, stress analysis in metals and soils. Limit analysis of beams, plates and shells. Shakedown. Selected topics in dynamic plasticity.

1269 Thermal Stresses. Fall term. Credit two hours. Offered in alternate years. Mr. Boley.
A treatment of the behavior of solids and structures at elevated temperatures. Thermomechanical coupling, inertia effects. Review of heat conduction in solids. Thermally induced vibrations. Elastic and inelastic stress analysis. Thermal buckling.

1270 Energy Methods in Solid Mechanics. Spring term. Credit two hours. Offered in alternate years. Mr. Boley.
A study of the various energy methods used in structural analysis. Principle of virtual work. Strain energy and complementary energy theorems. Reciprocal theorems. Elastic and inelastic analyses. Dynamical problems. Energy stability criteria.

1280 Composite Materials (Materials Science and Engineering 6625). Spring term. Credit three hours. Joint staffing: Theoretical and Applied Mechanics and Materials Science and Engineering.
The physical basis of the strength, elastic modulus, and fracture resistance of composite materials; the micro- and macromechanics of composites, their mechanical response, and important composite systems including fabrication, processing, and design applications. Compatibility and interaction of fibers and matrix. Fatigue, creep, fracture mechanisms. Analysis of primary configurations such as tension and compression members, beams, and plates including such local effects as bonding, fiber-tip stress concentration, buckling.

1290 Continuum Mechanics and Thermodynamics. Fall term. Credit three hours. Mr. Dafermos.
Kinematics. Conservation laws. The entropy inequality. Constitutive equations. Frame indifference. Material symmetry. Simple materials and the position of the classical theories in the framework of modern continuum mechanics.

1291 Continuum Mechanics and Thermodynamics of Solids. Spring term. Credit three hours. Prerequisite: 1290. Offered in alternate years.
Theory of (nonlinear) elasticity and thermoelasticity: universal solutions, wave propagation, stability theory. Nonlinear viscoelasticity and introduction to more general theories of solids.

1292 Continuum Mechanics and Thermodynamics of Fluids. Spring term. Credit three hours. Prerequisite: 1290. Offered in alternate years.
Viscometric flows of non-Newtonian fluids. Theory of mixtures. Oriented media and the theory of liquid crystals.

Dynamics and Vibrations

1362 Vibration of Elastic Systems. Fall term. Credit four hours. Three lectures, one laboratory. Mr. Pao.
Review of vibration of linear lumped systems with emphasis on matrix and transient phenomena. Free and forced vibration of continuous systems, including strings, rods, beams, membranes, and plates. Waves in rods and beams. Orthogonality conditions and application of generalized functions. Rayleigh-Ritz method. Mathieu function and dynamic instability of strings, columns, and other elastic systems. Nonlinear phenomena.

1366 Stress Waves in Solids. Spring term. Credit three hours. Offered in alternate years.
General equations of elastodynamics. Waves in extended elastic media. Reflection and refraction of waves. Surface waves and waves in layered media. Vibrations and waves in strings, rods, beams, and plates. Dispersion in mechanical wave-guides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in anisotropic media and viscoelastic media.

1370 Intermediate Dynamics. Fall term. Credit three hours. Mr. Alfriend.
Newtonian mechanics for single particles and systems of particles, conservation laws, central force motion; rigid body mechanics, Euler's equations, tops, gyroscopes; generalized coordinates, introduction to Lagrangian mechanics, Hamilton's principle; small oscillations. At the level of McCusky, *Introduction to Advanced Dynamics.*

1371 Advanced Dynamics. Spring term. Credit three hours. Mr. Alfriend.
Lagrangian mechanics, principle of least action, Hamilton's principle; Hamilton's canonical equations of motion, Hamilton-Jacobi theory, perturbation theory, quantum mechanics, special relativity. At the level of Goldstein, *Classical Mechanics.*

1375 Nonlinear Vibrations. Spring term. Credit three hours. Prerequisite: 1362 or equivalent. Offered in alternate years. Mr. Rand.
Phase plane techniques, singular points, conservative systems, limit cycles, Poincaré-Bendixson theorem, Poincaré's cycles without contact, method of isoclines, Lienard's method, Lyapunov stability, Floquet theory, Hill's and Mathieu's equation, perturbation

methods, method of Krylov and Bogoliubov. Emphasis on applications throughout.

Experimental Mechanics

1459 Experimental Mechanics. Fall term. Credit three hours. Mr. Robinson.

The student is expected to perform four to six experiments selected to meet his individual interests. Available experiments include: elastic waves in rods, viscoelastic waves and internal damping, linear vibrations of beams and plates, nonlinear response of elastic plates; two- and three-dimensional photoelasticity; plastic response of structures; magnetoelastic buckling of a beam-plate; gyroscopic motion; linear oscillators and analog computers.

Space Mechanics and Aerospace Structures

1730 Aerospace Structures I (Civil Engineering 2730). Fall term. Credit three hours. Offered in alternate years.

Evolution of aerospace structural design concepts and the structural design cycle. Environment, structural design inertia, and specifications for aircraft, missiles, and spacecraft. Inertia loads, load factors, flight envelopes, gust loads. Aerodynamic and solar heating, loads in space flight. Materials of construction and their properties; elastic and inelastic behavior, fatigue. Theories of failure. Fracture mechanics. Elementary structural analysis.

1731 Aerospace Structures II (Civil Engineering 2731). Spring term. Credit three hours. Offered in alternate years.

Structural problems and configurations of aircraft, missiles, and spacecraft. Analysis and design of thin-walled members in bending, torsion, and combined loadings. Reinforced stressed skin construction, thick shell construction, sandwich and composite materials. Inelastic analyses; plastic and viscoelastic behavior. Buckling, torsional instability, and crippling of thin-walled beams; creep buckling. Buckling and postbuckling behavior of plates, effective width. Thermal stresses and high temperature effects.

1772 Space Flight Mechanics. Fall term. Credit three hours. Mr. Rand.

Gravitational potential of the earth; two-body problem; three-body problem; restricted three-body problem; Jacob's integral; Hill curves; libration points and stability. Lagrange's planetary equations; effect of oblate earth, atmospheric drag and solar radiation on satellite orbits; satellite attitude control; orbital transfer and orbital maneuvers; rendezvous problems.

1773 Mechanics of the Solar System. Spring term. Credit three hours. Prerequisite: 1370 or consent of instructor. Mr. Burns.

The course applies the principles of mechanics (mainly dynamics but also elasticity) to explain some large-scale physical phenomena in the solar system. An understanding of the interplanetary environment will also be developed during the course. The topics covered will include: seismic waves and the free oscillations of the earth; gravitational potential of planets and their rotation; tidal interactions and Roche's limit; dynamics of the earth-moon system; spin-orbit coupling for Mercury and Venus; dynamics of comets, interplanetary dust and energetic charged particles; perihelion precession of Mercury; theories of the origin of the solar system.

1774 Trajectory Optimization. Spring term. Credit three hours. Prerequisite: 1772 or consent of the instructor. Offered in alternate years.

Review of calculus of variations. Optimal impulsive trajectories. Maximum principle, bounded controls, singular arcs and bounded state variables. Numerical methods, gradient techniques, quasilinearization. Applications to minimum time and minimum fuel orbit transfer, rendezvous, and interplanetary trajectories.

Bionics

[1857 Bionics and Robots (Electrical Engineering 4588). Spring term. Credit three hours. Prerequisite: elementary differential equations, linear algebra and probability, or consent of the instructor. Not offered in 1970–71. Mr. Block.

Interactions between engineering and biology. The mechanization of biological functions such as learning, seeing, hearing, recognition, recall, instinctual behavior, guessing, theorem proving, game playing, navigating, exploring, cognition, homeostasis, optimization, adaptation, heuristic reasoning, communication, language acquisition and translocation, self-organization, self-reproduction and self-repair, embryogenesis, growth, evolution and ecology. Cybernetics, information, reliable systems from unreliable components. Models: hardware, simulation analysis. Neural nets, perceptrons, threshold logic, madelines, features in patterns. Artificial intelligence. Computers and the foundations of mathematics, Gödel's theorem, Turing machines, computability. Finite-state machines and alegbraic linguistics.]

Special Courses

1996 Research in Theoretical and Applied Mechanics. Either term. Credit as arranged. Staff.

Thesis, literature survey, or independent research on a subject of theoretical and applied mechanics under the guidance of a staff member.

1997 Selected Topics in Theoretical and Applied Mechanics. Either term. Credit as arranged. Staff.

Special lectures or seminars on subjects of current interest in the Field; topics to be announced.

Water Resources

Faculty
David J. Allee, Richard D. Black, Leonard B. Dworsky, Alfred W. Eipper, Louis M. Falkson, Charles D. Gates, Lawrence S. Hamilton, George A. Kiersch, Gilbert Levine, Daniel P. Loucks, Walter R. Lynn, Paul J. Zwerman

Field Representative
C. D. Gates, 221 Hollister Hall

MINOR SUBJECT
Water Resources

This Field offers qualified engineers and biological, physical, and social scientists an opportunity to gain breadth of knowledge in water resources planning and management at the same time that they increase their depth of knowledge in their own disciplines. Study in the major subject is complemented by an interdisciplinary program of study in a minor subject designated as Water Resources.

The water resources minor will represent for each candidate that combination of courses, including core courses, seminars, and projects, outside his own discipline, which his Special Committee considers likely to meet his needs and interests in the comprehensive aspects of his total program.

Complementing major subjects are ordinarily chosen from the list below (Fields and faculty as shown).

Aerial Photographic Studies (Civil Engineering): D. J. Belcher, T. Liang, G. B. Lyon, A. J. McNair
Aquatic Ecology (Ecology and Evolutionary Biology): J. P. Barlow, G. E. Likens
Chemical Engineering (Chemical Engineering): V. H. Edwards, R. K. Finn
City and Regional Planning (City and Regional Planning): C. Riordan, K. C. Parsons
Economic Theory (Economics): L. M. Falkson
Engineering Geology (Geological Sciences): A. L. Bloom, G. A. Kiersch, S. S. Philbrick
Environmental Systems Engineering (Civil Engineering): L. M. Falkson, W. R. Lynn
Fishery Science (Conservation): A. W. Eipper, J. L. Forney, D. A. Webster
Geohydrology and Hydrogeology (Geological Sciences): G. A. Kiersch, S. S. Philbrick
Hydraulics and Hydrology (Civil Engineering): W. H. Brutsaert, J. A. Liggett
Limnology (Entomology and Limnology): C. O. Berg, J. M. Kingsbury, R. T. Oglesby
Meteorology (Agronomy): B. E. Dethier, W. W. Knapp
Natural Resources Conservation (Conservation): L. S. Hamilton, R. J. McNeil, B. T. Wilkins
Operations Research (Operations Research): H. Emmons, S. Stidham, H. M. Taylor
Public Administration (Business and Public Administration): E. S. Flash
Resource Economics (Agricultural Economics): D. J. Allee, R. J. Kalter
Sanitary Engineering (Civil Engineering): V. C. Behn, L. B. Dworsky, C. D. Gates, A. W. Lawrence, R. C. Loehr
Soil and Water Engineering (Agricultural Engineering): R. D. Black, G. Levine
Soil Science (Agronomy): M. G. Cline, R. D. Miller, P. J. Zwerman
Water Resource Systems (Civil Engineering): D. P. Loucks

Index of Fields of Instruction and Major and Minor Subjects

General Index

Graduate School Calendar, 1970–71

FALL TERM	*1970–71*
Registration, new students	Sept. 10
Registration, continuing students	Sept. 11
Fall term instruction begins, 7:30 a.m.	Sept. 14
Last day for filing statement-of-courses forms and change-of-committee forms and for new students to file nomination-of-committee forms	Sept. 25
Last day for old students to take admission-to-candidacy examinations in order to have them considered as of the beginning of the term	Oct. 15
Citizenship recess:	
Instruction suspended, 1:10 p.m.	Oct. 24
Instruction resumed, 7:30 a.m.	Nov. 5
Last day for change of course registration	Nov. 20
Thanksgiving Day, a holiday	Nov. 26
Christmas recess:	
Instruction suspended, 4:30 p.m.	Dec. 22
Instruction resumed, 7:30 a.m.	Jan. 4
Fall term instruction ends, 1:10 p.m.	Jan. 9
Independent study period begins, 2:00 p.m.	Jan. 9
Final examinations begin	Jan. 13
Last day for completing all requirements for a January degree	Jan. 15
Final examinations end	Jan. 20
Intersession begins	Jan. 21

SPRING TERM	
Registration, new and rejoining students	Jan. 28
Registration, continuing students	Jan. 29
Spring term instruction begins, 7:30 a.m.	Feb. 1
Last day for filing fellowship and scholarship applications for the following year	Feb. 1
Last day for filing statement-of-courses forms and change-of-committee forms and for new students to file nomination-of-committee forms	Feb. 12
Last day for old students to take admission-to-candidacy examinations to have them considered as of the beginning of the term	March 1
Spring recess:	
Instruction suspended, 1:10 p.m.	March 27
Instruction resumed, 7:30 a.m.	April 5
Last day for change of course registration	April 9
Spring term instruction ends, 1:10 p.m.	May 15
Independent study period begins	May 17
Final examinations begin	May 24
Last day for completing all requirements for a June degree	May 24
Final examinations end	June 1
Commencement Day	June 7

SUMMER	
Summer Research period begins	June 2
Registration for Summer Session	June 21 (8-week)
	June 30 (6-week)
Last day for filing statement-of-courses forms and change-of-committee forms and for new students to file nomination-of-committee forms	July 7
Summer Session ends	Aug. 13
Last day for completing all requirements for September degree	Aug. 27
Summer Research period ends	Sept. 10

Graduate School Calendar, 1971–72 (Tentative)

FALL TERM	*1971–72*	
Registration, new students	Sept.	9
Registration, continuing	Sept.	10
Fall term instruction begins, 7:30 a.m.	Sept.	13
Last day for filing statement-of-courses forms and change-of-committee forms and for new students to file nomination-of-committee forms	Sept.	24
Last day for old students to take admission-to-candidacy examinations in order to have them considered as of the beginning of the term	Oct.	14
Last day for change of course registration	Nov.	19
Thanksgiving recess:		
Instruction suspended, 1:10 p.m.	Nov.	24
Instruction resumed, 7:30 a.m.	Nov.	29
Fall term classes end, 1:10 p.m.	Dec.	18
Christmas recess	Dec.	18
Last day for completing all requirements for a January degree	Jan.	7
Independent study period begins	Jan.	3
Final examinations begin	Jan.	10
Final examinations end	Jan.	18
Intersession begins	Jan.	19

SPRING TERM		
Registration, new students	Jan.	27
Registration, continuing students	Jan.	28
Spring term instruction begins, 7:30 a.m.	Jan.	31
Last day for filing fellowship and scholarship applications for the following year	Feb.	1
Last day for filing statement-of-courses forms and change-of-committee forms and for new students to file nomination-of-committee forms	Feb.	11
Last day for old students to take admission-to-candidacy examinations to have them considered as of the beginning of the term	Feb.	28
Spring recess:		
Instruction suspended, 1:10 p.m.	March	25
Instruction resumed, 7:30 a.m.	April	3
Last day for change of course registration	April	7
Spring term classes end, 1:10 p.m.	May	13
Independent study period begins	May	15
Last day for completing all requirements for a June degree	May	22
Final examinations begin	May	22
Final examinations end	May	30
Commencement	June	5

SUMMER			
Summer Research period begins	May	31	
Registration for Summer Session	June	19	(8-week)
	June	28	(6-week)
Last day for filing statement-of-courses forms and change of-committee forms and for new students to file nomination-of-committee forms	July	5	
Summer Session ends	Aug.	11	
Last day for completing all requirements for a September degree	Aug.	28	
Summer Research period ends	Sept.	8	