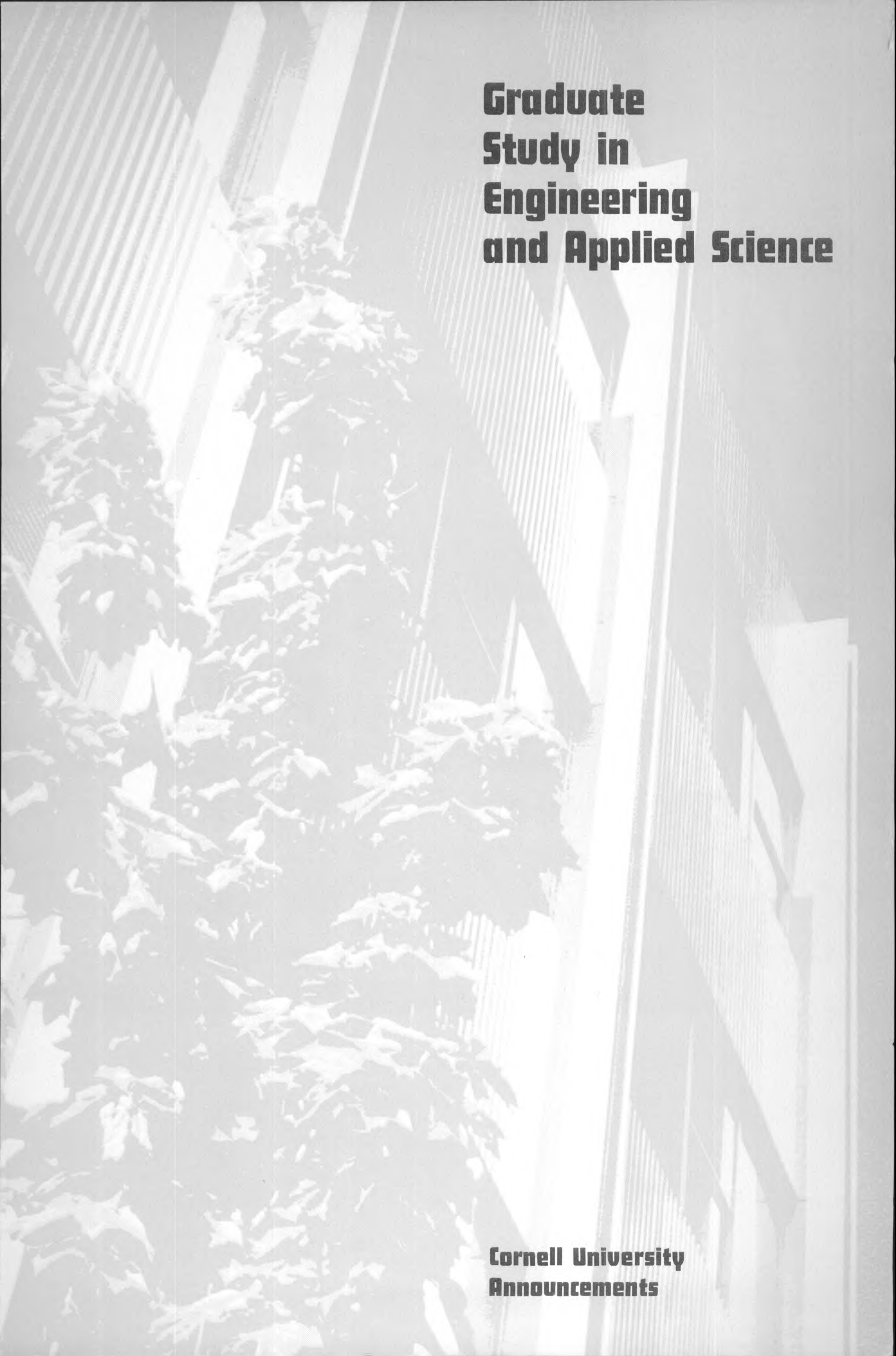
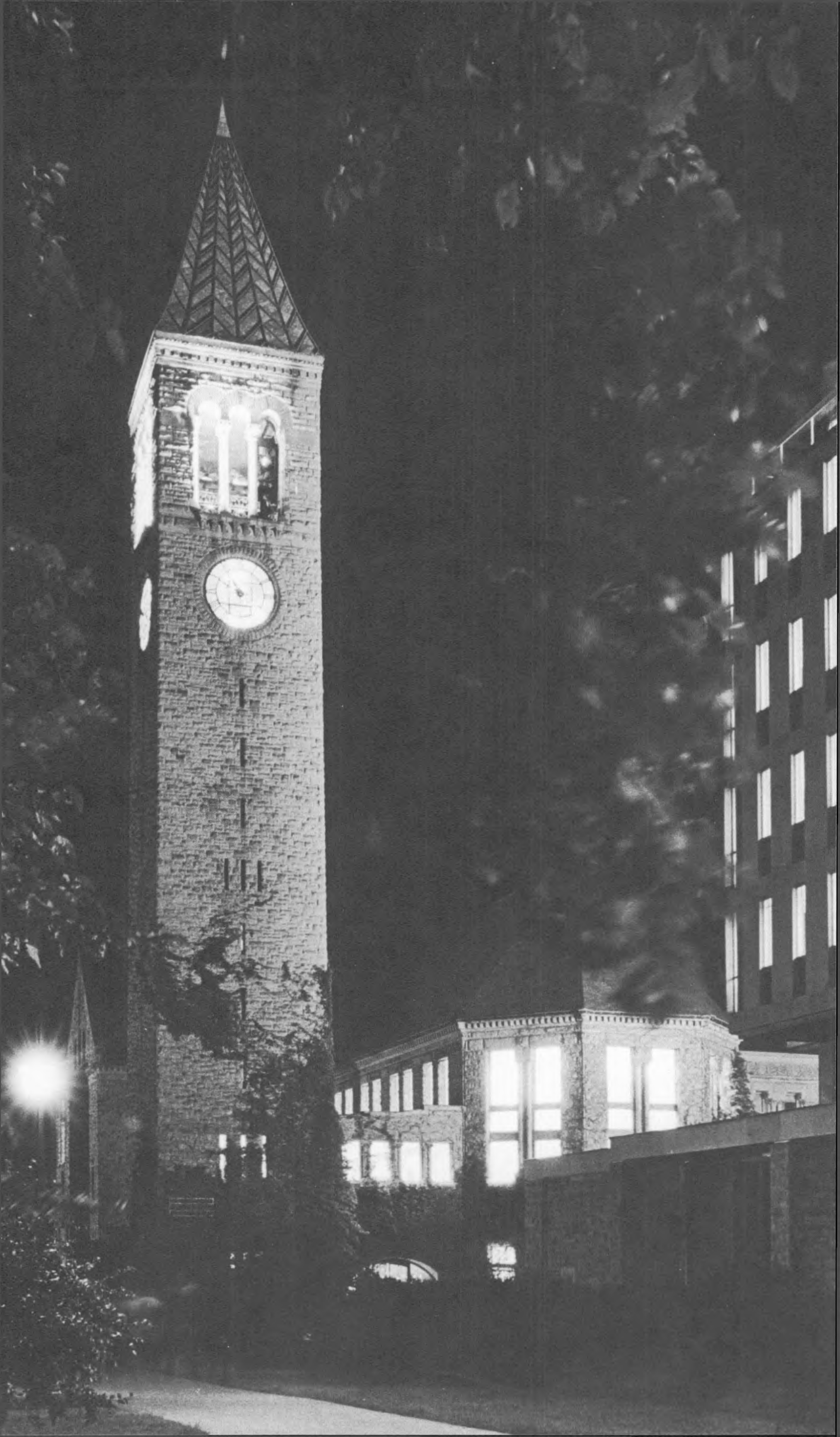


Graduate Study in Engineering and Applied Science

Cornell University Announcements

Graduate Study in Engineering and Applied Science

Cornell University
Ithaca, New York



Contents

Cornell University Announcements

Volume 66 of the Cornell University Announcements consists of twenty-two catalogs, of which this is number 3, dated January 11, 1974. Publication dates: twenty-two times a year (four times in August; three times in January and March; twice in June, July, September, and November; once in April, May, October, and December). Publisher: Cornell University, Sheldon Court, 420 College Avenue, Ithaca, New York 14850. Second-class postage paid at Ithaca, New York.

Graduate Study in Engineering and Applied Science

At Cornell, graduate study in engineering and applied science is conducted within the context of a large and diverse university with international reputation. The faculty and facilities of the College of Engineering provide a foundation for graduate education in these areas, but the resources of the entire University are available to each graduate student in accordance with his or her particular needs and interests.

About 650 students are now working toward advanced degrees in the various fields of engineering and applied science at Cornell. Some of these students are working in the research-oriented Master of Science and Doctor of Philosophy degree programs, and some are enrolled in professional Master of Engineering degree programs. In the M.S. and Ph.D. degree programs, instruction is offered by University faculty members organized into graduate fields of instruction. The professional degree programs are generally supervised by the faculty of specific schools or departments of the College of Engineering. All graduate programs at Cornell are administered by the University's Graduate School.

The M.S. and Ph.D. Program

The prospective student who wishes to specialize in an engineering or related subject at the M.S. or Ph.D. level must first decide which graduate field offers the course work and research opportunities best suited to his plans and interests, for admission to the programs is determined by the faculty of the individual fields. It may be noted that the separation of graduate programs into fields is necessarily somewhat arbitrary: some areas of research are interdisciplinary in nature, and some of the fields draw on faculty members in related departments or areas. The descriptions, in this *Announcement,* of various graduate fields and their areas of activity may be helpful to the student in his choice.

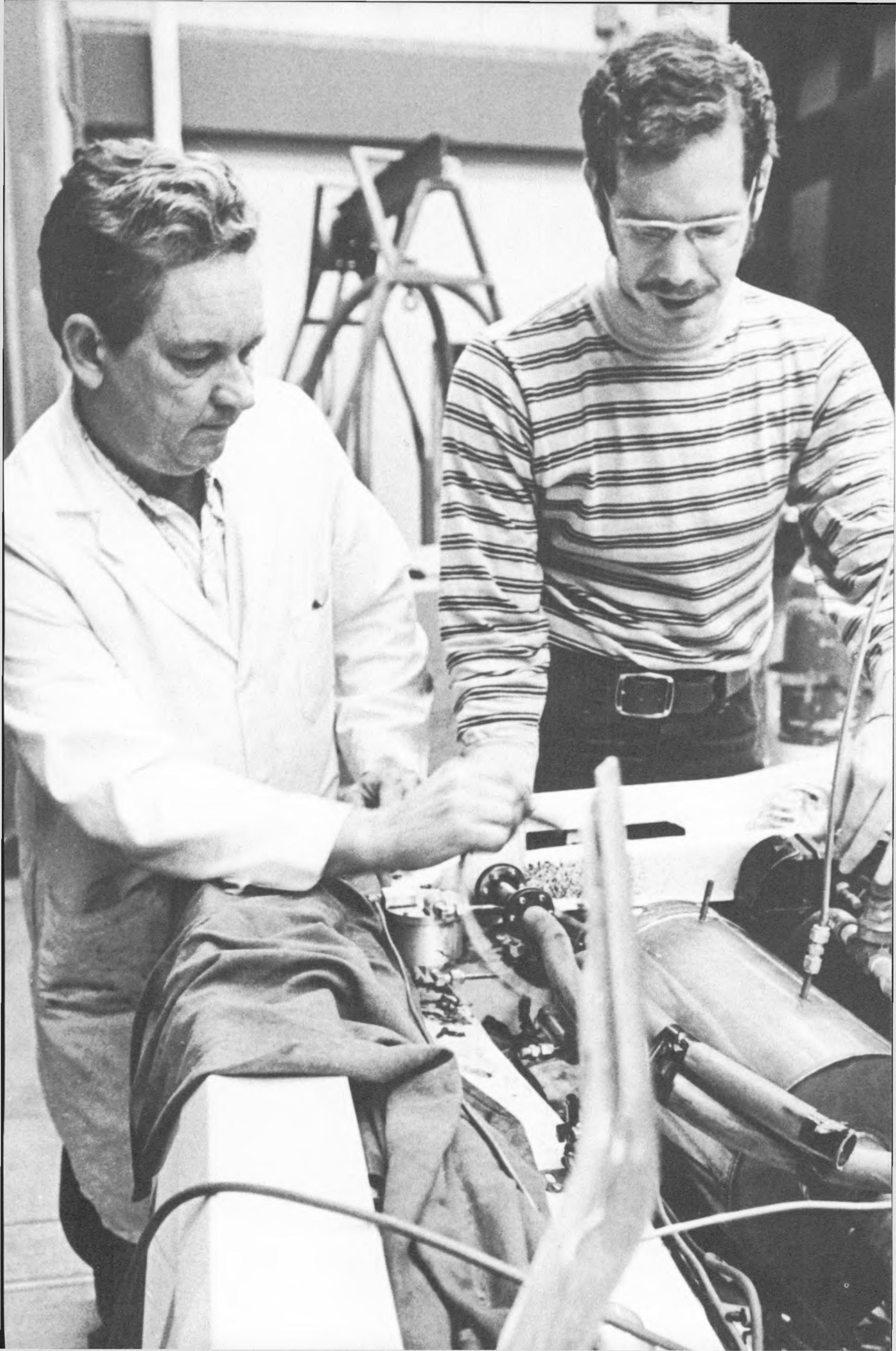
The ten modern buildings on the Engineering Quadrangle are located at the south side of the Cornell campus, bordering the scenic Cascadilla Gorge.

The M.S. or Ph.D. candidate also selects his Special Committee, headed by the professor who will supervise his studies and including two additional faculty members. The information in this publication may be helpful in this selection. The Special Committee has an unusually important position in graduate education at Cornell, for it is wholly responsible for overseeing the student's course of study and progress, and for deciding when he is ready to receive his degree. This committee is usually chosen toward the beginning of the student's residency. If he experiences changes in interests as he progresses in his studies, however, he may modify his committee at some later time.

Although the Graduate School sets no course, credit-hour, or grade requirements, leaving these matters to the discretion of each Special Committee, the graduate faculty has established general requirements, including a minimum term of residence, an oral examination, and submission of a thesis based on supervised research. Detailed information on Graduate School procedures, requirements, costs, financial aid, etc., is given in the *Announcement of the Graduate School.* Course descriptions are given in the *Announcement of the Graduate School: Course Descriptions.*

The Master of Engineering Degree Program

The professional Master of Engineering program, intended for students who wish to prepare for professional engineering careers, offers another option for advanced study. The M.Eng. programs are often pursued by Cornell students who begin an integrated three-year curriculum in the junior year of undergraduate study, but they are open to graduates of other four-year engineering schools. Degrees are awarded in eleven areas: aerospace engineering; engineering physics; engineering mechanics; and agricultural, chemical, civil, electrical, industrial, materials, mechanical, and nuclear engineering. These programs and specific courses are described in more detail in the *Announcement of the College of Engineering.*



The Graduate Fields

Aerospace Engineering

Aerospace engineering, traditionally concerned with the flight of aircraft, guided missiles, and space vehicles, is constantly expanding the frontiers of its technology and encountering new problems which are often interdisciplinary in nature. The objective of graduate programs in aerospace engineering at Cornell is to educate selected engineering and science graduates for research and advanced development in this science and technology. About twenty-five students are currently enrolled in the graduate Field of Aerospace Engineering and in the Master of Engineering (Aerospace) program. Students who plan to work for the Ph.D. degree are encouraged to matriculate first in the M.Eng. program.

In the curriculum, emphasis is placed on the aerospace and associated sciences, as well as on current design practice; consequently, students are encouraged to take courses in physics, mathematics, chemistry, astronomy, and allied engineering subjects in order to strengthen their understanding of fundamentals. Offered by the Field are courses in fluid mechanics, gasdynamics, advanced thermal physics, plasma dynamics, dynamics of rarefied gases, aircraft structures, space mechanics, theory of viscous flows, hypersonic flow theory, acoustics and aerodynamic noise, and atmospheric motions.

Also of interest to aerospace engineering students are graduate courses offered by the closely related Field of Mechanical Engineering. At Cornell, these two disciplines are joined in the Sibley School of Mechanical and Aerospace Engineering. The two Fields conduct a joint weekly colloquium to help students keep informed on research and developments in both areas. Another cooperative activity is the weekly research conference, at which students regularly present summaries of their research progress and students and staff members are encouraged to make comments and suggestions. Graduate students find this conference particularly helpful in the early phases of research.

In a current graduate research project at the Sibley School of Mechanical and Aerospace Engineering, internal combustion engines are modified to effect reduction of air pollution.

Direct contact between faculty members and students is emphasized. Students are also encouraged to help each other solve their research problems. The entire Field operates as a research group, and a friendly, informal atmosphere has always prevailed.

Facilities

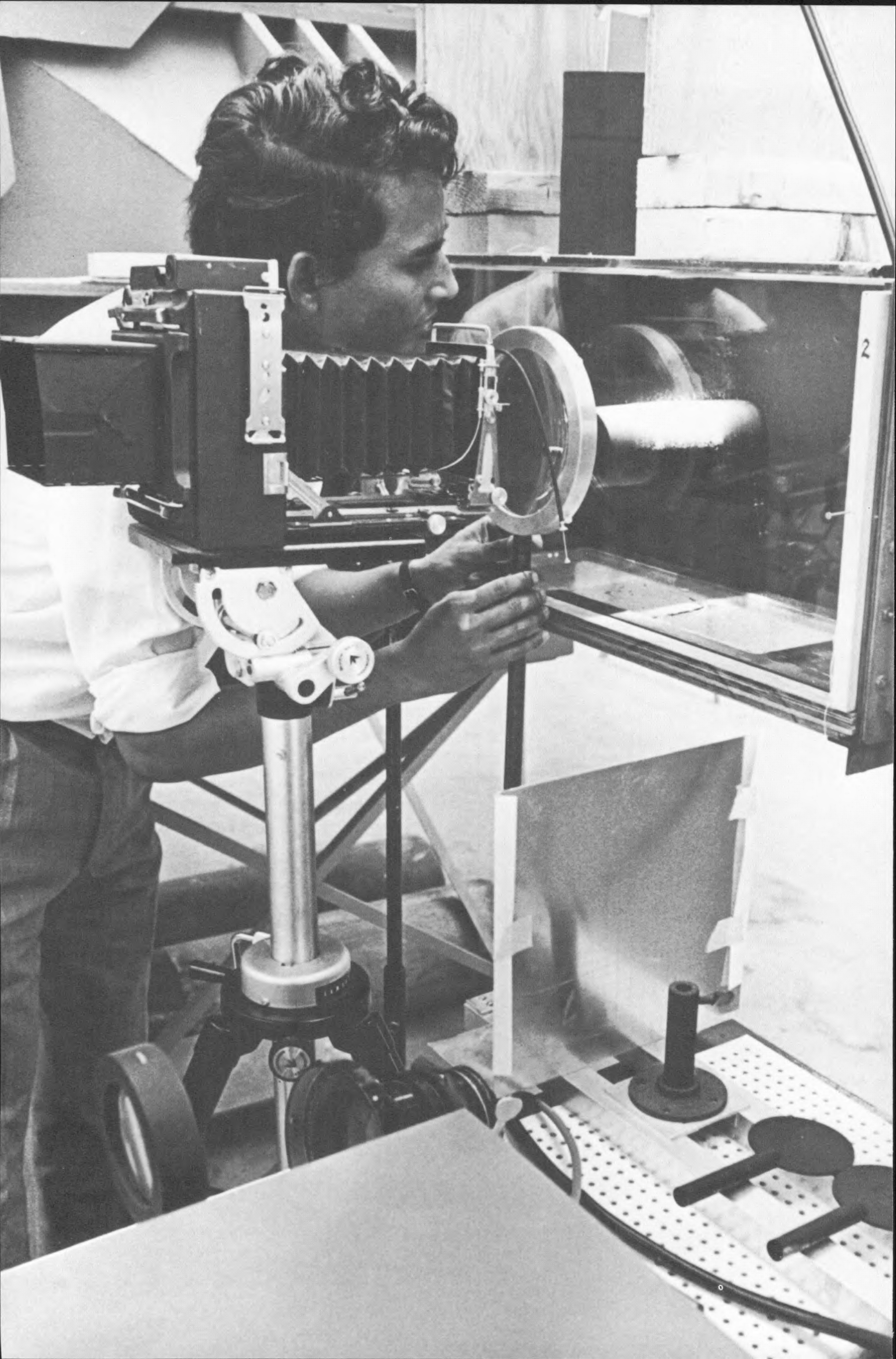
Superior experimental facilities are available for laboratory studies in such areas as basic fluid mechanics, aerodynamics, gasdynamics and gas chemistry, hypersonics, rarefied gasdynamics, magnetohydrodynamics, plasma dynamics, laser chemistry, sonic boom, aerodynamic noise, geophysical fluid dynamics, radiation gasdynamics, ferro-fluidics, and general acoustics.

The Field has a long history of pioneer work in the development of the shock tube as a research tool for studying chemical kinetics and electrically conducting gases and for supporting studies in fusion plasmadynamics and laser chemistry.

A facility currently under construction, in cooperation with the College of Architecture, Art, and Planning, is a wind tunnel for the study of peculiarities of flow around tall buildings.

Areas of Research

The Field of Aerospace Engineering maintains an emphasis on research in basic fluid mechanics, aerodynamics, shock tubes, magnetohydrodynamics, sonic boom, geophysical flow problems, and related aspects of studies in pollution control and atmospheric dynamics. Current projects include several involving aerodynamic noise associated with compressors, turbines, and helicopters. Also under way are sound propagation studies designed to find methods for controlling the noise of aircraft, particularly around airports. The propagation of sonic boom through the atmosphere and associated phenomena are being investigated.



Various fundamental and applied aerodynamic problems characterized by unsteady effects are subjects of another research project. Also, attempts are being made, from the viewpoint of fluid mechanics, to understand convection cells driven by radioactivity inside the earth and the moon, and their geophysical consequences. In other areas of research, the possibilities of fusion power are being explored and pollution control is being studied. The development of computing techniques, especially the finite-element method for the solution of fluid mechanical problems, is being actively pursued.

Examples of research topics are indicated by the following list of recent publications:

Bauer, S. H.; Lederman, D. M.; Resler, E. L., Jr.; and Fisher, E. R. 1973. The homogeneous gas phase H_2-D_2 metathesis at room temperature: Reaction induced by specific vibrational excitation. *International Journal of Chemical Kinetics* V:93.

deBoer, P. C. T. 1973. Ion boundary layer on a flat plate. *AIAA Journal* 11(7):1012.

Kuscer, I. and Shen, S. F. 1972. Effect of gas-surface interaction on the transmission of sound through a collisionless gas. *Transport Theory and Statistical Physics* 2(3):227.

Ludford, G. S. S., and Olunloyo, V. 1972. The forces of a flat plate in a Couette flow. *Journal of Applied Mathematics and Physics* 23:115.

Plotkin, K. J., and George, A. R. 1972. Propagation of weak shock waves through turbulence. *Journal of Fluid Mechanics* 54(3):449.

Sears, W. R. 1973. Self-Correcting Wind Tunnels. 16th Lanchester Lecture, to be published by the Royal Aeronautical Society.

Seebass, A. R. 1973. The design or operation of aircraft to minimize their sonic boom. American Institute of Aeronautics and Astronautics paper no. 73–817.

Turcotte, D. L.; Hsui, A.-T.; and Torrance, K. E. 1972. Thermal structure of the moon. *Journal of Geophysical Research* 77(35):6931.

The following doctoral theses are representative of the research recently accomplished by aerospace engineering students:

Chu, T.-C. 1971. Focusing of Finite-Amplitude Cylindrical and Spherical Sound Waves in a Viscous and Heat Conducting Medium. Ph.D. thesis. (Professor Seebass.)

David, T. S. 1971. Spherical and Cylindrical Electric Probes in a Continuum Flowing Plasma. Ph.D. thesis. (Professor deBoer.)

Farassat, F. 1973. The Sound from Rigid Bodies in Arbitrary Motion. Ph.D. thesis. (Professor Sears.)

Graduate research on boundary layer separation involves flow visualization of the aerodynamics of a rotating cylinder in a stream.

Hiestand, J. W. 1973. A Generalized Steady State Approximation for the Numerical Solution of Sets of Ordinary Differential Equations with Widely Differing Time Constants. Ph.D. thesis. (Professor George.)

Homicz, G. 1973. Broadband and Discrete Frequency Noise Radiation from Subsonic Rotors. Ph.D. thesis. (Professor George.)

Hsui, A. T.-K. 1972. A Numerical Study of Finite Amplitude Thermal Convection and its Geophysical Implications. Ph.D. thesis. (Professor Turcotte.)

Hung, C.-M. 1972. Reflection of a Weak Shock Wave with Vibrational Relaxation from a Wall. Ph.D. thesis. (Professor Seebass.)

Jones, J. R. 1973. Vibrational Relaxation Time of Carbon Dioxide at Low Temperature. Ph.D. thesis. (Professor deBoer.)

Kot, S.-C. 1971. Beam-Continuum Model for Hypersonic Flows. Ph.D. thesis. (Professor Seebass.)

Lederman, D. M. 1973. Laser-Induced Atom Exchange. Ph.D. thesis. (Professor Resler.)

Meixel, G. 1973. Injection of High-Current Relativistic Electron Beams into a Torus. Ph.D. thesis. (Professor Auer.)

Osborne, C. 1971. Compressibility Effects in the Unsteady Interaction between Blade Rows. Ph.D. thesis. (Professor Sears.)

Robb, B. S. 1972. Laser-Produced Spherical Shock Waves. Ph.D. thesis. (Professor Turcotte.)

Yu, N.-J. 1974. Heat-Induced Flow and its Applications. Ph.D. thesis. (Professor Resler.)

Faculty Members and Their Research Interests

Peter L. Auer, Ph.D. (California Institute of Technology): *plasma dynamics; high-power lasers; nonlinear plasma phenomena*

P. C. Tobias deBoer, Ph.D. (Maryland): *gasdynamics and gas chemistry; plasma dynamics; kinetic theory of gases; gasdynamics; automotive pollution control*

Richard H. Gallagher, P.E., Ph.D. (SUNY-Buffalo): *structures*

Albert Richard George, Ph.D. (Princeton): *hypersonics; fluid dynamics; aerothermochemistry; sonic boom; aerodynamic noise; general acoustics*

Geoffrey S. S. Ludford, Ph.D., Sc.D. (Cambridge): *applied mathematics; fluid mechanics; magnetohydrodynamics*

Edwin L. Resler, Jr., Ph.D. (Cornell): *gasdynamics and gas chemistry; ferrohydrodynamics; laser aerodynamics*

William R. Sears, Ph.D. (California Institute of Technology): *fluid mechanics; aerodynamics; magnetohydrodynamics; aerodynamic noise*

A. Richard Seebass, III, Ph.D. (Cornell): *fluid mechanics; aerodynamics; hypersonics; magnetohydrodynamics; sonic boom*

Shan-fu Shen, Sc.D. (M.I.T.): *rarefied gasdynamics; stability of flows; aerodynamics; radiation gasdynamics; computational fluid mechanics*

Donald Lawson Turcotte, Ph.D. (California Institute of Technology): *magnetohydrodynamics; plasma dynamics; aerothermochemistry; rarefied gasdynamics; geophysical fluid dynamics*

The regular faculty is supplemented by distinguished visitors from the United States and abroad. Visitors have included Hannes Alfvén, G. K. Batchelor, J. M. Burgers, L. F. Crabtree, Nima Geffen, Isao Imai, Theodore von Kàrmàn, J. W. Linnett, P. S. Lykoudis, F. E. Marble, R. S. B. Ong, E. R. Oxburgh, D. A. Spence, Ko Tamada, and Itiro Tani.

Further Information

Further information may be obtained by writing to: Field Representative, Aerospace Engineering, Upson Hall, Cornell University, Ithaca, New York 14850.

A graduate student performs an experiment in a study of isotope exchange reaction induced by laser radiation.

Agricultural Engineering

The application of engineering to agriculture is necessarily a very broad field of work and study. Agricultural engineering has an intrinsic dependence upon both the physical and biological sciences, and involves many interdisciplinary specialties.

Accordingly, diversity also marks the nature of graduate research in the field of Agricultural Engineering at Cornell. This diversity is manifest in the theses submitted by graduate students: they may be entirely experimental or entirely theoretical, but more frequently they are a blending of the two. The availability of strong programs in the physical, biological, and engineering sciences at Cornell and the diversity of faculty interests permits an unusually wide range of choice in areas of specialization.

In the Field of Agricultural Engineering there are approximately thirty graduate students who come from all over the United States and many other parts of the world. Virtually all of them receive financial support from either the University or external sources.

A student may enter one of four programs leading to advanced degrees in agricultural engineering: Doctor of Philosophy, Master of Science, Master of Engineering (Agricultural), or Master of Professional Studies (Agriculture). For the Ph.D. and M.S. degrees, original research and presentation of a thesis are required; the student's Special Committee, a faculty group chosen by the student, is solely responsible for the direction of the curriculum and research program. The M.Eng. program is intended to prepare the student for the practice of engineering, and the M.P.S. program provides an opportunity for advanced study in agriculture. For these professional degrees, emphasis is placed upon advanced course work and project development and there is no thesis requirement.

Machines and methods for the mechanical harvesting of fruits and vegetables are being developed in agricultural engineering projects.

In addition to their course work in agricultural engineering subjects, graduate students are encouraged to take courses in the basic sciences and advanced mathematics in order to strengthen their understanding of fundamentals. To assist the graduate students in keeping abreast of current developments, a general seminar is held weekly during the academic year and specialized seminars are conducted by individual research groups during the spring term.

Facilities

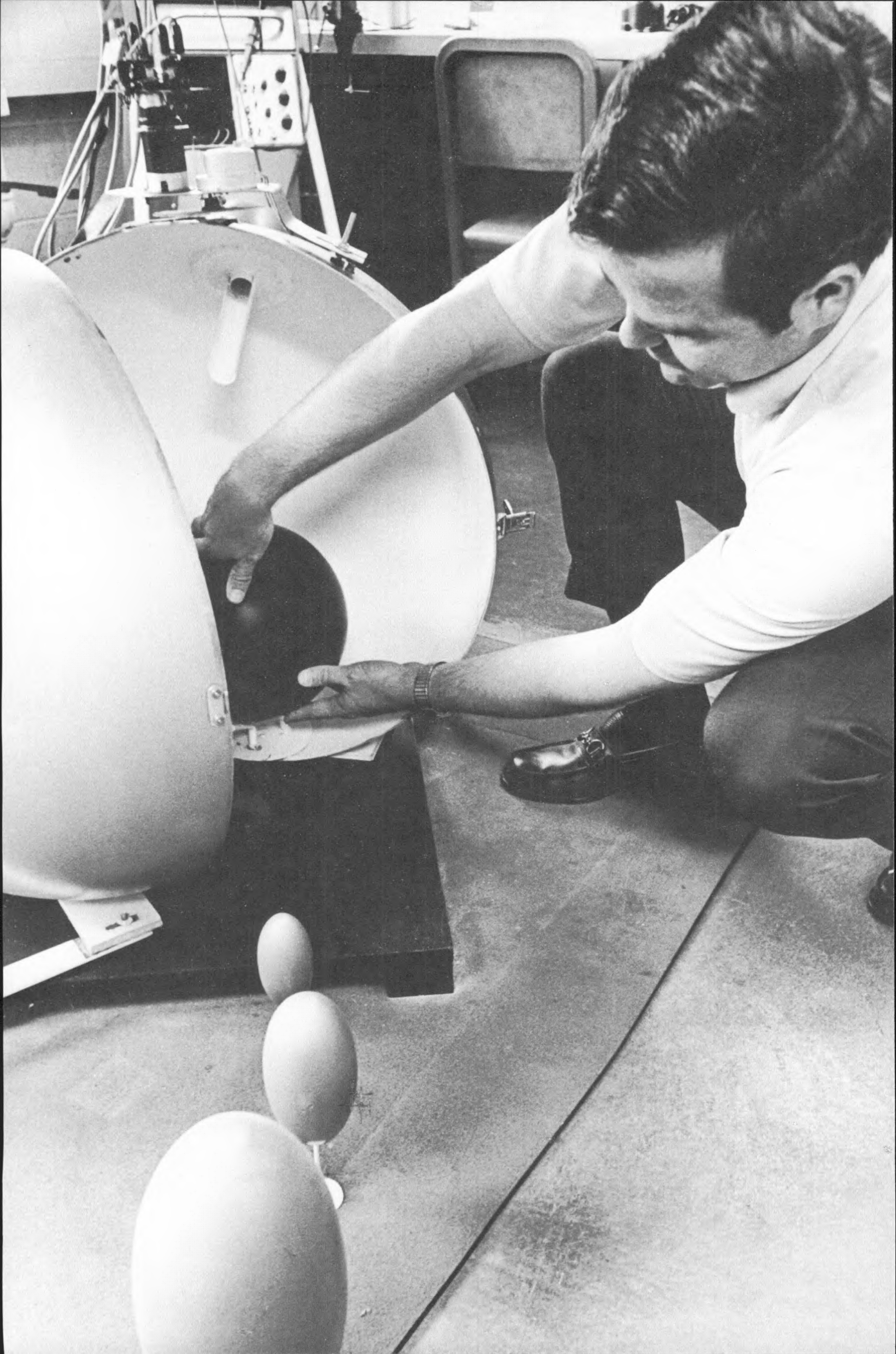
Riley-Robb Hall, a modern facility with 100,000 square feet of floor space, provides a center for the graduate programs in agricultural engineering at Cornell. Major laboratories in the building include those for agricultural waste management research, for small animal calorimetry and environmental physiological studies, and for work in the controlled atmospheric storage of agricultural materials. In addition, there is a well equipped machine shop to implement the development of prototype equipment such as machines for the mechanical harvesting of fruits and vegetables.

Other facilities include the nearby Agricultural Waste Management Laboratory, which is operated by the Department of Agricultural Engineering for pilot-plant studies, the Animal Science Teaching and Research Center, and plant growth chambers. Available to graduate students are the central computing system of the University, several programmable calculators, and a University library that ranks among the ten largest in the United States.

Areas of Research

The diversity of the overall field of agricultural engineering and the breadth of the programs at Cornell are demonstrated by the variety of research projects now underway.

The mechanization of fruit and vegetable



harvesting is a continuing major area of study and development. Product conditioning and extended storage life have been the goals of research on corn, onions, and cabbage.

The mathematical modeling of biological systems has been used extensively for both the description and prediction of biological phenomena. These studies have been conducted at several levels, ranging from cellular considerations, as in the behavior of guard cells and their role in controlling transpiration, to microbial studies, as in the denitrification of agricultural wastes, to the organism or multicelluar level, such as in investigations of the mechanics of growth, to the level of larger ecological communities, such as in studies of strategies for the reduction of undesirable effects of agricultural production upon the environment.

Agricultural waste management research has been directed primarily to ways of minimizing the deleterious effects associated with poultry waste disposal.

Some specific research projects are discussed in more detail below, and examples are given of associated thesis work and journal publications.

Engineering Studies of Biological Systems: Plant and Animal

Knowledge of the biology of plants and animals, and of their mechanical and other physical properties, is becoming increasingly important in agricultural engineering design. For example, the high priority given to the mechanization of the harvesting, handling, and processing of all economically important fruits and vegetables has stimulated a greater interest in the engineering properties of plant materials. Environmental factors affecting plant growth are being studied in order to more intelligently design the tools and the machines used in crop production. These studies have been concerned with the plant's response to its environment from germination to storage. The work includes studies of optimum levels of plant population, the environment needed for seed germination, the precision placement of seeds, and factors such as the heat and moisture transfer in the seedbed, oxygen diffusion to the germinating seed, and the ability of roots to penetrate compacted soils. Other investigations are concerned with the assessment of the textural properties of fruits and vegetables and with the preservation of these products in storage through regulation of the gaseous environment.

Animal production (of milk, eggs, or meat, for example) is known to be affected by environmental, nutritional, and pathological conditions. Basic information is needed on those physiological mechanisms that limit animal productivity and are influenced by the environment. At Cornell, biomathematical modeling, direct and indirect animal calorimetry, telemetry, and analog simulation techniques have been applied in attempts to understand the influences of environmental factors on animal systems.

In a continuing program in mechanical harvesting, techniques and equipment have been developed for harvesting cabbage, lettuce, grapes, cherries, and apples for processing. Research is now being concentrated on the harvesting of fresh market apples, and prototype equipment capable of operating within reasonable bruise damage tolerances is being developed. The automatic sorting of products on the basis of quality is also being studied.

Examples of publications that have resulted from work in this area are:

Cooke, J. R., and Rand, R. H. 1973. A mathematical study of resonance in intact fruits and vegetables using a 3-media elastic sphere model. *Journal of Agricultural Engineering Research* 18:141.

Furry, R. B. 1972. Postharvest Storage of Cabbage: Problems and Prospects. ASAE paper no. 72–877. Presented at the meeting of the American Society of Agricultural Engineers, December 1972, in Chicago.

Gunkel, W. W., et al. 1972. New developments in artificial drying—a method for control of botyris neck rot on bulk stored onions. In *29th annual progress report, New York Farm Electrification Council,* p. 43.

Millier, W. F., and Brown, G. K. 1973. *Citrus fruit appearance, weight loss, and internal condition inferences for mechanical harvesting.* Report no. ARS-W-5 of the Agricultural Research Service, U.S. Department of Agriculture.

Price, D. R.; Heathington, K. W.; and Peart, R. M. 1972. Computer simulation of dairy milking parlors. *Transactions of the American Society of Agricultural Engineers* 15(2):317, 323.

Rehkugler, G. E. 1972. Technique for routine stress analysis of the hen's egg. *Transactions of the American Society of Agricultural Engineers* 15(6):1086.

Scott, N. R., and Johnson, A. T. 1972. Telemetry system and heart rate counter for determination of heart rate of small animals. *Transactions of the American Society of Agricultural Engineers* 15(1):14, 23.

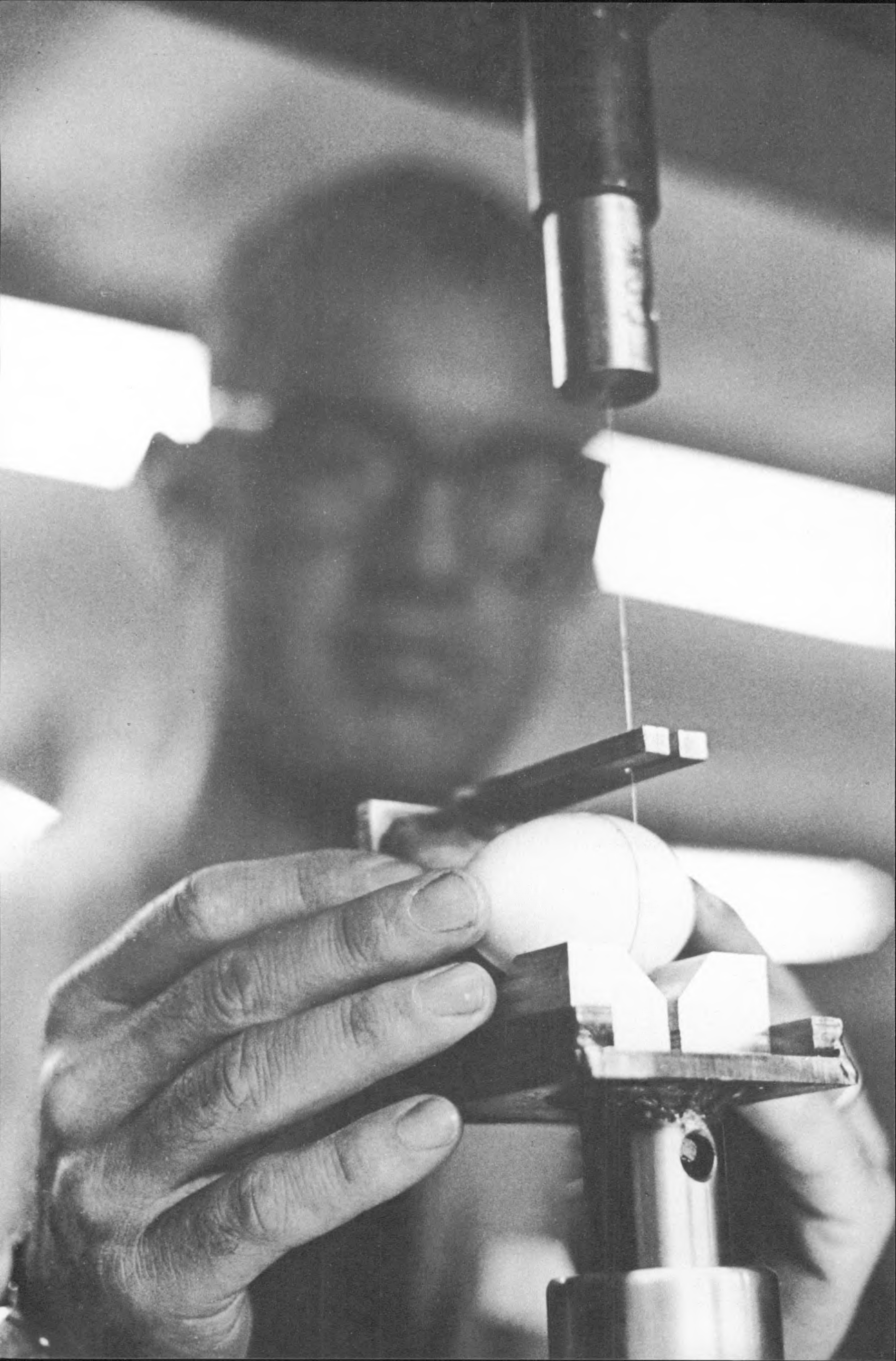
Shepardson, E. S.; Pollock, J. G.; and Rehkugler, G. E. 1973. Research and Development of a Lettuce Harvester. ASAE paper no. 71–693. Chicago, Illinois: American Society of Agricultural Engineers.

Recent theses that illustrate the research projects undertaken by graduate students who are specializing in this area are:

Garrett, R. E. 1970. Velocity of Propagation of Mechanical Disturbances in Apples. Ph.D. thesis. (Professor Furry.)

Hauk, R. W. 1971. Soil Temperature and Moisture Fields Predicted by a System of Coupled Equations. Ph.D. thesis. (Professor Cooke.)

Geometric shapes employed as standards await their turn during calibration of an infrared reflectance measuring system used to evaluate quality changes in plant specimens.



Haung, T. 1971. Theoretical and Experimental Studies of the Heating Front in a Deep Bed Hygroscopic Product. Ph.D. thesis. (Professor Gunkel.)

Hussain, A. A. M. 1971. Dynamic Behavior of Tree Limbs Forced by an Intermittent Harmonic Displacement. Ph.D. thesis. (Professor Rehkugler.)

Kenyon, D. E. 1973. A Binary Mixture Theory for Fluid Suspensions. Ph.D. thesis. (Professor Scott.)

McLendon, B. D. 1973. Simulation of Intergrating Sphere Evaluation of Diffuse Reflectance of Intact Biological Specimens. Ph.D. thesis. (Professor Furry.)

Miles, J. A. 1971. The Development of a Failure Criterion for Apple Flesh. Ph.D. thesis. (Professor Rehkugler.)

Parchomchuk, P. 1971. Vibratory Fruit Harvesting: An Experimental Investigation of an Apple Fruit-Stem Response to Forced Oscillations. M.S. thesis. (Professor Cooke.)

Townsend, J. S. 1969. A Mathematical Modeling Approach to the Study of the Mechanics of Milking Machine Operation. Ph.D. thesis. (Professor Shepardson.)

Engineering Studies of Physical Systems

Certain research and engineering design studies can be carried out without regard for the biological context in which the physical problems arise; that is, in certain circumstances, physical considerations provide the overriding constraints. This approach is used in several projects by Field members and their students.

The accelerating trend toward highly specialized farmstead production systems presents challenges for research related to the physical aspects of handling, processing, and storage of agricultural products. Associated areas of research include structural design, spatial organization, and enclosure conditioning. The design of specialized agricultural equipment, such as a leaf baler, a stone-soil separator, snow-removal equipment, and highway litter removal equipment, are examples of projects in this general area.

Research on the design of low-volume roads continues to be a major concern. Facilities for research in road materials include equipment for performing physical tests on soils and highway materials, stabilized soils, and bituminous paving mixtures. Studies of the utilization of power-plant wastes in highway construction and of highway-drainage systems under flood conditions are underway.

Measurement of the amount of stress needed to cause fracture of an egg shell is part of the experimental work in a study of factors that influence the strength of poultry egg shells.

Among faculty publications on these subjects are:

Gunkel, W.W.; Kahl, W. H.; and Moffett, L. 1972. Mechanical planting of pineapples—automation concept in design. In *International conference on tropical and subtropical agriculture; conference papers*, special publication SP-01-72, p. 242. St. Joseph, Michigan: American Society of Agricultural Engineers.

Millier, W. F.; Rehkugler, G. E.; Pellerin, R. A.; Throop, J. A.; and Bradley, R. B. In press. A tree fruit harvester with an insertable multilevel catching system. *Transactions of the American Society of Agricultural Engineers*, paper no. 72–651.

Price, D. R., and Peart, R. M. 1973. Simulation model to study the utilization of waste heat using a combination multiple reservoir and greenhouse complex. *Journal of Environmental Quality* 2(2):216.

Some of the recent theses in this area of research are:

Albright, L. D. 1972. The Low Speed Nonisothermal Wall Jets with Applications to Ventilation. Ph.D. thesis. (Professor Scott.)

Davis, D. C. 1973. Simulation and Model Verification of Agricultural Tractor Over-Turns. Ph.D. thesis. (Professor Rehkugler.)

Maghsood, J. 1970. Finite Element Analysis of Wood Beams. Ph.D. thesis. (Professor Scott.)

Riley, J. G. 1971. The Road Corrugation Phenomenon: A Simulation and Experimental Evaluation. Ph.D. thesis. (Professor Furry.)

Waste Management

The agricultural waste management problem in the United States is as complex and challenging as the problem of improving the quality of our environment. The trend toward confinement feeding of livestock, the increasing size of food processing operations, and the high concentrations of waste per unit area, as well as the necessity to avoid water, air, and soil pollution, make imperative a successful attack on the waste management problems that are facing agriculture.

A well-equipped laboratory is available at Cornell for research on many aspects of waste management, including odor reduction and control, liquid waste treatment, handling and disposal techniques, waste characteristics, solid waste management, treatment process control, and systems analysis and modeling. A large pilot plant and a laboratory are available for demonstrating the handling and treatment processes that prove feasible on a smaller scale. Full scale field studies are underway to evaluate feasible alternatives.

Current research efforts include projects on tertiary treatment of animal waste waters; feasible handling and treatment processes and analytical models for animal waste management, poultry waste disposal, and odor control; dispersal and utilization of dairy and poultry manure by land application; poultry manure properties, handling, and disposal; the establishment of design parameters for agricultural waste-management systems; and management alternatives for dealing with wastes from egg breakage.

Recent publications on these subjects include:

Haith, D. A. 1974. Optimal control of nitrogen losses from land disposal areas. *Proceedings of the American Society of Civil Engineers* (forthcoming).

Jewell, W. J., ed. 1973. *Rural environmental engineering: Proceedings of a national conference.* Boston: New England College Press.

Loehr, R. C. 1973. *Agricultural waste management—problems, processes and approaches.* New York: Academic Press.

Ludington, D. C.; Sobel, A. T.; Loehr, R. C.; and Hashimoto, A. G. 1972. Pilot plant comparison of liquid and dry waste management systems for poultry manure. In *Proceedings of the 1972 Cornell agricultural waste management conference,* p. 569. Washington, D.C.: Graphics Management.

Recent theses on topics in waste management include:

Aung-Din, R. 1972. The Algal Growth Potential of Various Poultry Waste Management Alternatives. M.S. thesis. (Professor Loehr.)

Baker, D. R. 1973. Oxygen Transfer Relationships in a Poultry Waste Mixed Liquor. M.S. thesis. (Professor Loehr.)

Hashimoto, A. G. 1972. Ammonia Desorption from Concentrated Chicken Manure Slurries. Ph.D. thesis. (Professor Ludington.)

Holmes, B. 1973. The Effect of Drying Time on Nitrogen Losses from Poultry Manure. M.S. thesis. (Professor Ludington.)

Nelson, D. M. 1973. A Study of Destructive Distillation of Egg Farm Wastes. M.S. thesis. (Professor Loehr.)

Schulte, D. D. 1973. Simulation of Nitrogen Losses from Poultry Production Facilities. Ph.D. thesis. (Professor Loehr.)

Wong-Chong, G. 1973. Kinetics of Microbial Nitrification as Applied to the Treatment of Animal Waste. Ph.D. thesis. (Professor Loehr.)

Soil and Water Engineering

The general area of surface hydrology is being studied by several groups in the Field. This subject deals with the application of engineering principles to problems of soil and water control in agriculture, and is concerned with the design and construction of drainage systems, and the development and evaluation of irrigation systems. Specific research interests at the present time are the hydraulics of response to agricultural practices and soil-plant-water relationships.

Research relating to the engineering problems of tropical irrigation has been conducted for a number of years. Particular attention is given to the study of the impact of design on water management. Students working in this program conduct their field research overseas; current studies are being conducted in the Philippines and Brazil.

Examples of journal publications on these subjects are:

Dunne, T., and Black, R. D. 1970. An experimental investigation of runoff characteristics in permeable soils. *Water Resources Research* 6(20):478.

Kampen, J., and Levine, G. 1970. Water losses and water balance studies in Philippine lowland rice irrigation. *Philippine Agriculturalist* LIV (5 and 6):283.

Some recent theses in this area are:

Burman, R. D. 1969. Plot Runoff Using Kinematic Wave Theory and Parameter Optimization. Ph.D. thesis. (Professor Black.)

Early, A. C. 1973. The Influence of Water Management on Operating Policies for Sugar Cane Districts in the Philippines. Ph.D. thesis. (Professor Levine.)

Kampen, J. 1970. Water Losses and Water Balance Studies in Lowland Rice Irrigation. Ph.D. thesis. (Professor Levine.)

Wickham, T. H. 1971. Water Management in the Humid Tropics: A Farm Level Analysis. Ph.D. thesis. (Professor Levine.)

Projects Under Development

In addition to the areas of research described above, certain other aspects of agricultural engineering will be receiving special attention in the near future. These areas include efficiency of energy utilization in agricultural production, food engineering, safety and fire protection engineering, and the engineering aspects of rural community and resource development.

Research will be conducted on the agricultural production and processing utilization of energy resources, and on agricultural usage of thermal wastes produced by the generation of electricity. Energy production from agricultural wastes will receive special attention. An interdisciplinary community and resource development research program will include studies of the flood resistance of farm structures, mobile homes, and highway drainage structures.

Faculty Members and Their Research and Teaching Interests

Richard D. Black, P. E., Ph.D. (Illinois): *drainage of agricultural land; small watershed hydrology; soil conservation structures*

J. Robert Cooke, Ph.D. (North Carolina State): *biological engineering; environmental control of* *plants and plant growth; engineering properties of biological materials; mathematical engineering analysis*

Edward W. Foss, M. S. A. (Cornell): *safety engineering; community resources development; the teaching of agricultural mechanization*

Ronald B. Furry, Ph.D. (Iowa State): *plant and animal structures and environments; controlled-atmosphere storage of fruits and vegetables; similitude methodology*

Richard W. Guest, P. E., M. S. (North Dakota State): *mechanics of machine milking dairy cows; harvesting, storage, and utilization of high moisture corn*

Wesley W. Gunkel, Ph.D. (Michigan State): *design of specialized agricultural and industrial machinery; mechanical methods of disease control; seed environment*

Douglas A. Haith, Ph.D. (Cornell): *management of agricultural systems for environmental quality control; water resource systems*

Lynne H. Irwin, Ph.D. (Texas A&M): *highway engineering; highway materials evaluation; pavement design; soil stabilization; use of waste materials in highway construction; community and resource development*

William J. Jewell, Ph.D. (Stanford): *waste treatment and control; unit process development; rural environmental engineering; septic tanks; agricultural waste management*

Fred G. Lechner, Ed.D. (Michigan State): *the teaching of agricultural mechanization in secondary schools, two-year technical colleges, and four-year colleges*

Gilbert Levine, Ph.D. (Cornell): *irrigation system design; tropical irrigation; water management; soil-water-plant relationships*

Raymond C. Loehr, P. E., Ph.D. (Wisconsin): *waste treatment; process control; solid wastes; industrial wastes; treatment systems; agricultural waste management*

Robert T. Lorenzen, P. E., M. S. (California): *farmstead production systems design, including structural and environmental aspects of enclosures; functional tenets of systems*

David C. Ludington, Ph.D. (Purdue): *management of agricultural wastes to reduce air and water pollution*

Everett D. Markwardt, M. S. (Cornell): *mechanical fruit and vegetable harvesting; irrigation systems*

William F. Millier, P.E., Ph.D. (Cornell): *seed coating; crop establishment; tree fruit harvesting; farm machinery*

Donald R. Price, Ph.D. (Purdue): *electric power and processing; energy utilization; systems engineering analysis*

Richard H. Rand, Sc.D. (Columbia): *biomechanics; theoretical and applied mechanics; dynamical systems*

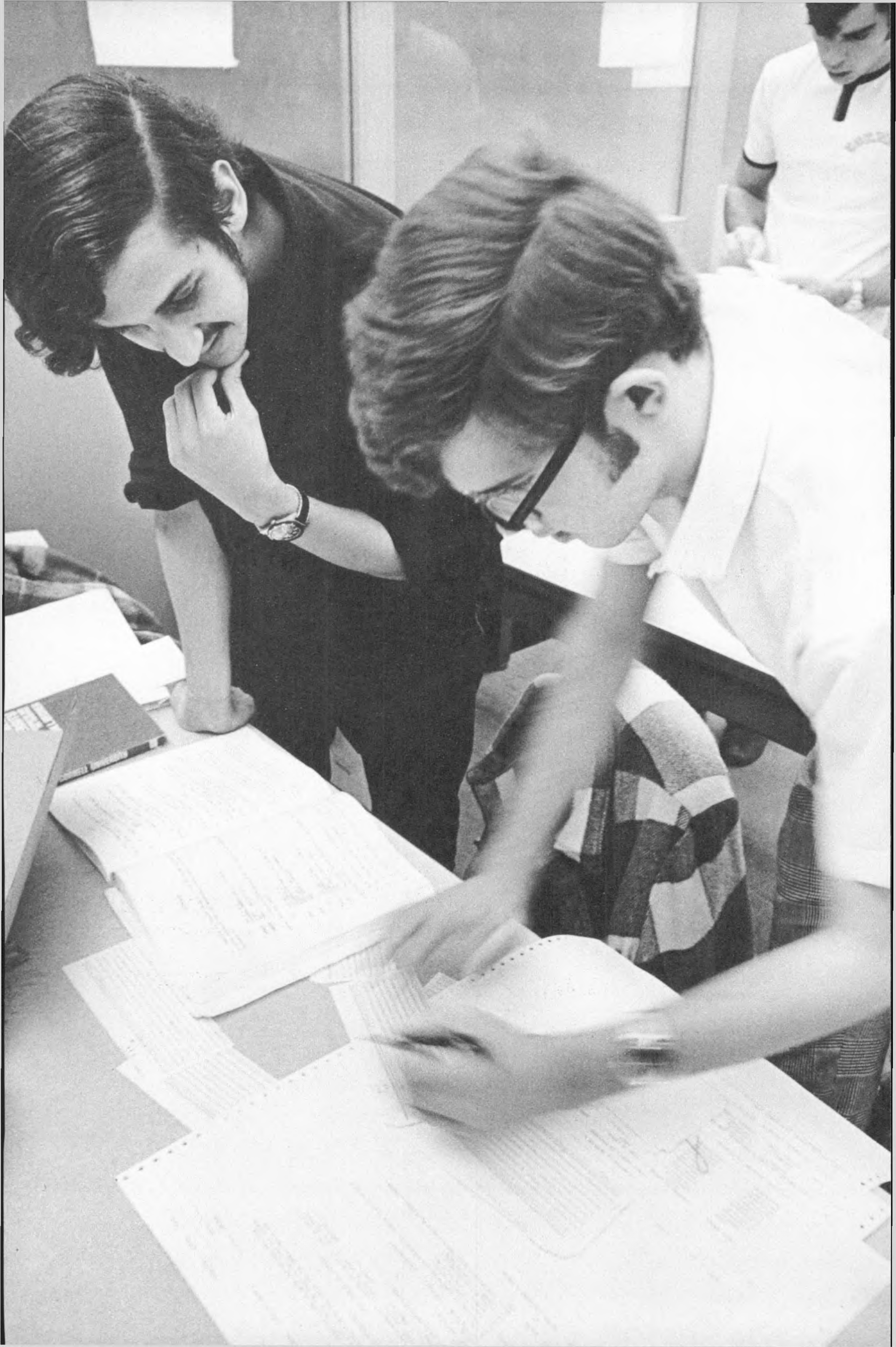
Gerald E. Rehkugler, P. E., Ph.D. (Iowa State): *mechanical harvesting of fruits and vegetables; physical properties of biological products; food engineering; use of internal combustion engines and other energy sources in agriculture*

Norman R. Scott, Ph.D. (Cornell): *biomathematical modeling of animal systems; animal calorimetry; environmental physiology; thermal environment; integrated application of structural theory, thermodynamics, and biological sciences to synthesis of structural systems; electronic instrumentation techniques in physical and biological measurements*

E. Stanley Shepardson, M. S. (Cornell): *power and machinery; mechanical harvesting; electric power and processing*

Further Information

The publication *Department of Agricultural Engineering: The Staff and Programs*, published each fall, contains information on current teaching, research, and extension activities of the Department of Agricultural Engineering. Included are descriptions of continuing and new research projects, listings of the faculty and staff members and graduate students involved in each project, and the major cooperating units in interdisciplinary projects. Requests for this publication and inquiries concerning any aspect of the graduate program may be directed to: Coordinator of Graduate Studies in Agricultural Engineering, Riley-Robb Hall, Cornell University, Ithaca, New York 14850.



Applied Mathematics

The achievements and methodology of classical and modern mathematics have in recent years proved most useful in a wide variety of other disciplines, including many new subject areas as well as the more traditional ones. At Cornell, the Field of Applied Mathematics offers a broadly based interdepartmental program with opportunities for study and research over a wide spectrum of the general mathematical sciences. This program is based on a solid foundation in pure mathematics which includes the fundamentals of algebra and analysis, as well as the methods of applied mathematics. The remainder of an individual student's program is designed in a free and flexible way by himself and his Special Committee, comprising three faculty members, so as to attain the goals which they set. The program is open to applicants from the various undergraduate backgrounds which contain a substantial mathematical component.

There are several different graduate programs at Cornell in which one can pursue studies of applied mathematics. Students with well defined interests in this general area should investigate the suitability of programs in the Fields of Computer Science, Mathematics, Operations Research, Statistics, and Theoretical and Applied Mechanics, as well as various fields in the physical sciences and engineering. The Field of Applied Mathematics is particularly appropriate for those interested in classical applied mathematics, or for those undertaking truly interdisciplinary studies involving mathematics but lying between the areas encompassed by other graduate fields.

Research and study in this Field is coordinated through the Center for Applied Mathematics. There are nearly forty core faculty members in the Center, and graduate students occasionally do their thesis research under additional faculty members not formally associated with this Field. The Center does not offer courses itself; its twenty-five Ph.D. students select courses from those offered by a dozen related academic departments. Each faculty member in the Center also holds an appointment in at least one of these departments.

Computer services are among the resources available to applied mathematics students.

Facilities

The Center for Applied Mathematics maintains faculty and student offices and seminar rooms in Olin Hall on the engineering campus. All facilities of the University, including, for example, computer services, are available to graduate students in the Field of Applied Mathematics.

Areas of Research

A large number of research possibilities exist for graduate students in this Field. These include the following topics, as well as combinations of them and their applications to other fields: Partial differential equations, numerical analysis, functional analysis, mathematical physics, mechanics, aerodynamics, fluid flow, magnetofluid dynamics, astrophysics, statistical mechanics, applied probability, statistics, mathematical biology, population growth, genetics, logic, automata, networks, combinatorics, game theory, and mathematical economics.

The following list of recent Ph.D. theses provides a sample of research activities in the Field.

Baker, G. A. 1973. Projection Methods for Boundary Value Problems for Equations of Elliptic and Parabolic Type with Discontinuous Coefficients. (Professor Bramble.)

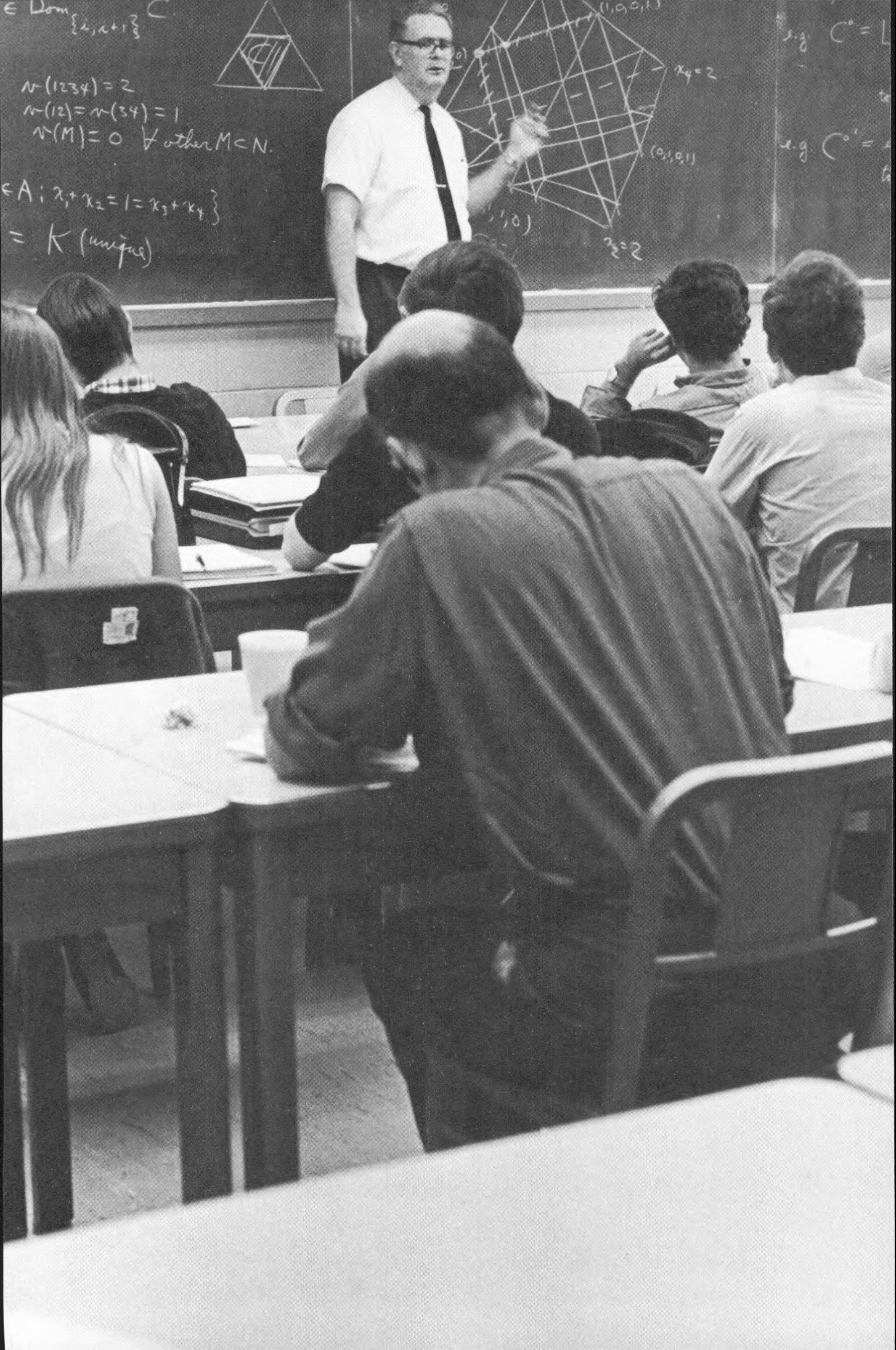
Bezdek, J. C. 1973. Fuzzy Mathematics in Pattern Classification. (Professor Dunn.)

Cook, L.P. 1971. The Asymptotic Behavior as $\varepsilon \rightarrow 0+$ of the Solution to $\varepsilon \triangle^2 \omega = (\delta / \delta y) \omega$ on a Rectangle. (Professor Ludford.)

Falk, R. 1971. Approximate Solutions of Some Variational Inequalities with Order of Convergence Estimates. (Professor Bramble.)

Hamilton, E. P. 1973. The Infinitely Renormalized Field in the Scalar Field Model. (Professor Gross.)

Harris, R. V., Jr. 1972. A Polynomial Bound on the Complexity of the Davis-Putnam Algorithm Applied to Symmetrizable Propositions. (Professor Constable.)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Hassard, B. D. 1972. The Effective Calculation of Eigenvalues as Applied to Problems of Hydrodynamic and Hydromagnetic Stability. (Professor Ludford.)

Kalai, E. 1972. Cooperative Non-Sidepayment Games: Extensions of Sidepayment Game Solutions, Matrices, and Representative Functions. (Professor Lucas.)

Khosrovshahi, G. B. 1972. Growth Properties of Solutions of Schrödinger Type Equations. (Professor Payne.)

Moore, M. H. 1971. Array Design for Optimum Signal Detection. (Professor Fine.)

Noble, D. 1971. Circuit Properties of Dispersive Coupled Transmission Lines and Waveguides. (Professor Carlin.)

Rueda, A. 1973. On the Non-Equilibrium Thermodynamics of Thermal Radiation Fields. (Professor Nelkin.)

Wohl, P. R. 1971. The Transverse Force on a Drop in Unbounded Poiseuille Flow. (Professor Rubinow.)

Faculty Members and Their Research Interests

Toby Berger, Ph.D. (Harvard): *information theory; statistical communication; random processes*

Louis J. Billera, Ph.D. (City University of New York): *game theory; combinatorial analysis; mathematical economics*

Henry D. Block, Ph.D. (Iowa State): *biomathematics; artificial intelligence; robot theory; environmental systems*

James H. Bramble, Ph.D. (Maryland): *numerical analysis; partial differential equations*

James R. Bunch, Ph.D. (California at Berkeley): *numerical algebra*

Herbert J. Carlin, Ph.D. (Polytechnic Institute of Brooklyn): *microwave and network techniques*

Robert Constable, Ph.D. (Wisconsin): *theory of computing; automata; logic*

John E. Dennis, Ph.D. (Utah): *numerical mathematics*

Joseph C. Dunn, Ph.D. (Adelphi): *optimal control theory; pattern classification*

Roger H. Farrell, Ph.D. (Illinois): *probability and statistics*

Terrence L. Fine, Ph.D. (Harvard): *decision theory; comparative probability; speech recognition*

Michael E. Fisher, Ph.D. (King's College, London): *foundations and applications of statistical mechanics; combinatorics*

Wolfgang H. J. Fuchs, Ph.D. (Cambridge): *mathematical methods of physics*

D. Ray Fulkerson, Ph.D. (Wisconsin): *mathematical programming; network flow theory*

Leonard Gross, Ph.D. (Chicago): *analysis; mathematics of quantum theory*

Frederick Jelinek, Ph.D. (M.I.T.): *information theory; coding; communication networks; automata*

James T. Jenkins, Ph.D. (Johns Hopkins): *nonlinear field theories in mechanics; continuum mechanics*

Harry Kesten, Ph.D. (Cornell): *probability theory*

Jack C. Kiefer, Ph.D. (Columbia): *probability and statistics*

James A. Krumhansl, Ph.D. (Cornell): *solid state physics; microscopic descriptions of macroscopic properties of materials*

Sidney Leibovich, Ph.D. (Cornell): *fluid dynamics; magnetohydrohynamics*

Simon A. Levin, Ph.D. (Maryland): *mathematical biology; differential equations*

Richard L. Liboff, Ph.D. (New York University): *kinetic theory; plasma physics; quantum mechanics*

William F. Lucas, Ph.D. (Michigan): *game theory; combinatorial mathematics*

Geoffrey S. S. Ludford, Sc.D. and Ph.D. (Cambridge): *fluid mechanics; magnetofluid dynamics*

Mukul K. Majumdar, Ph.D. (California at Berkeley): *mathematical economics*

Joseph Moré, Ph.D. (Maryland): *numerical analysis*

Anil Nerode, Ph.D. (Chicago): *mathematical logic; recursive functions and computability; automata*

Lawrence E. Payne, Ph.D. (Iowa State): *partial differential equations*

Narahari U. Prabhu, M.S. (Manchester): *stochastic processes; queues and inventories; reliability*

Richard H. Rand, Engr. Sc.D. (Columbia): *differential equations; dynamical systems; biomechanics*

Sol I. Rubinow, Ph.D. (Pennsylvania): *blood flow; cell proliferation*

Edwin E. Salpeter, Ph.D. (Birmingham): *theoretical astrophysics; nuclear theory; statistical mechanics*

Alfred H. Schatz, Ph.D. (New York University): *partial differential equations*

A. Richard Seebass, Ph.D. (Cornell): *aerodynamics; fluid dynamics*

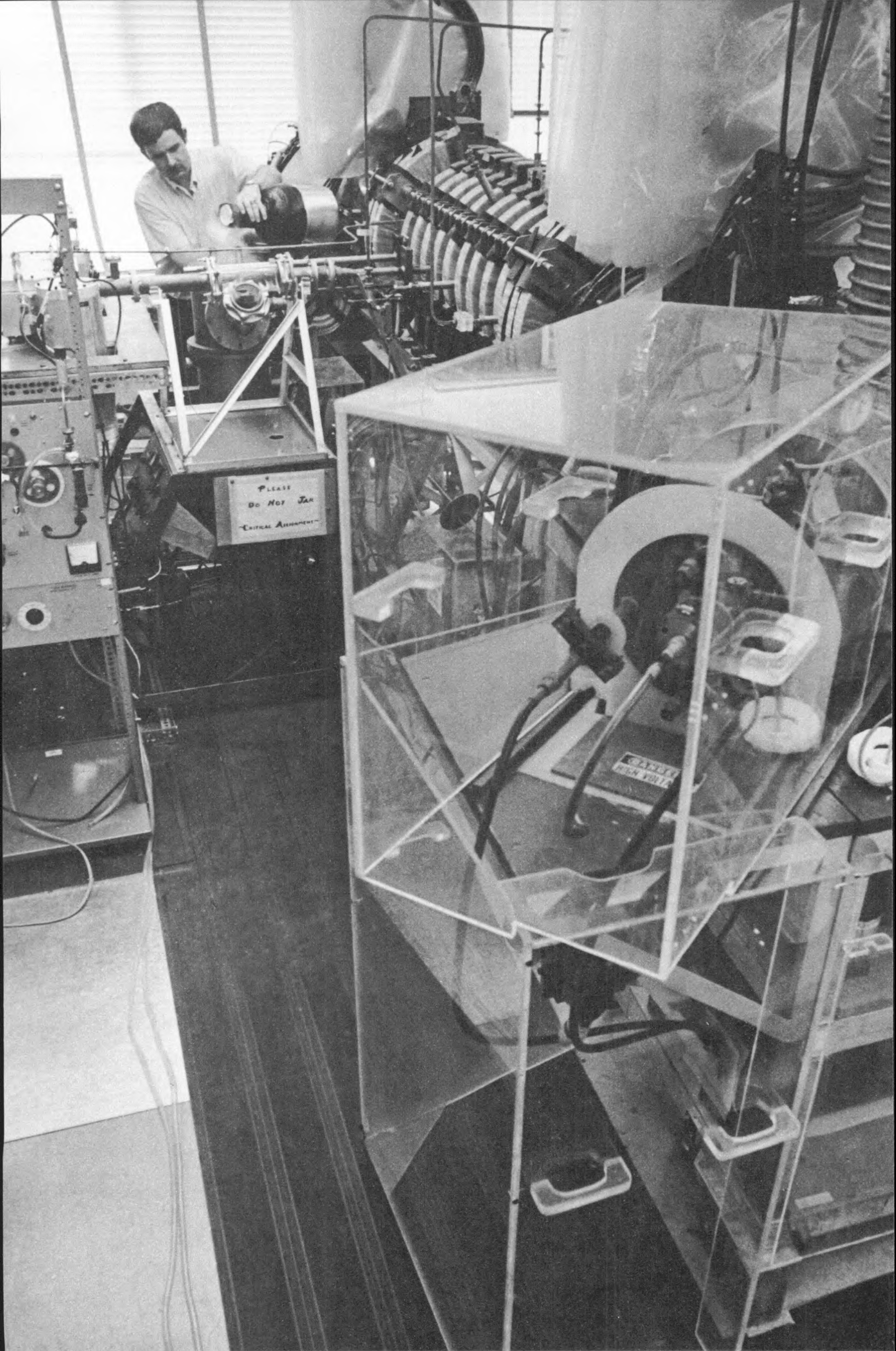
Shan-fu Shen, Sc.D. (M.I.T.): *aerodynamics; rarefied gas dynamics*

Frank L. Spitzer, Ph.D. (Michigan): *probability theory and analysis*

Benjamin Widom, Ph.D. (Cornell): *physical chemistry; statistical mechanics*

Further Information

Further information may be obtained by writing to: Graduate Field Representative, Center for Applied Mathematics, Olin Hall, Cornell University, Ithaca, New York 14850.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Applied Physics

The graduate Field of Applied Physics offers opportunities for the pursuit of advanced studies leading to original work in many areas of applied science in which the activity is based on the principles and techniques of physics. Programs available in the Field provide 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 a background in engineering or another science to extend their knowledge of basic physics.

Individual programs are planned to meet the needs and interests of each student. They may involve several academic disciplines and topics that are undergoing transition from fundamental physics to applied science. In addition to the M.S. and Ph.D. research-oriented programs offered by the Field of Applied Physics, there is available a one-year program leading to the professional degree of Master of Engineering (Engineering Physics). Approximately sixty students are now pursuing graduate studies for these degrees.

The Applied Physics faculty is centered in the School of Applied and Engineering Physics of the College of Engineering, but it includes members of various other departments of the University. Many members are associated with one or more of the interdisciplinary laboratories at Cornell, such as the Laboratory of Plasma Studies, the Materials Science Center, and the Center for Radiophysics and Space Research. This diversity permits graduate students to choose from an unusual range of specialty areas. An equally important benefit of the interdisciplinary nature of the Field is the extensiveness of research facilities that are available.

An important consideration in the choice of a field for graduate study is the availability of career opportunities; in the area of applied physics the prospects are good. Although the opportunities for careers in basic physics have substantially leveled off in recent years, there has been a strong long-range need in industry, government, and universities for graduates who not only have a sound education in physics but also have the capability for attacking practical problems. Approximately four out of five Cornell Applied Physics graduates assume positions with industrial organizations that are seeking to develop new technologies and new products. About one in five enters academic work, and a smaller number begin careers in governmental or related laboratories or programs.

Mechanisms for plasma heating by turbulence are being studied by means of microwave scattering and neutral particle analysis.

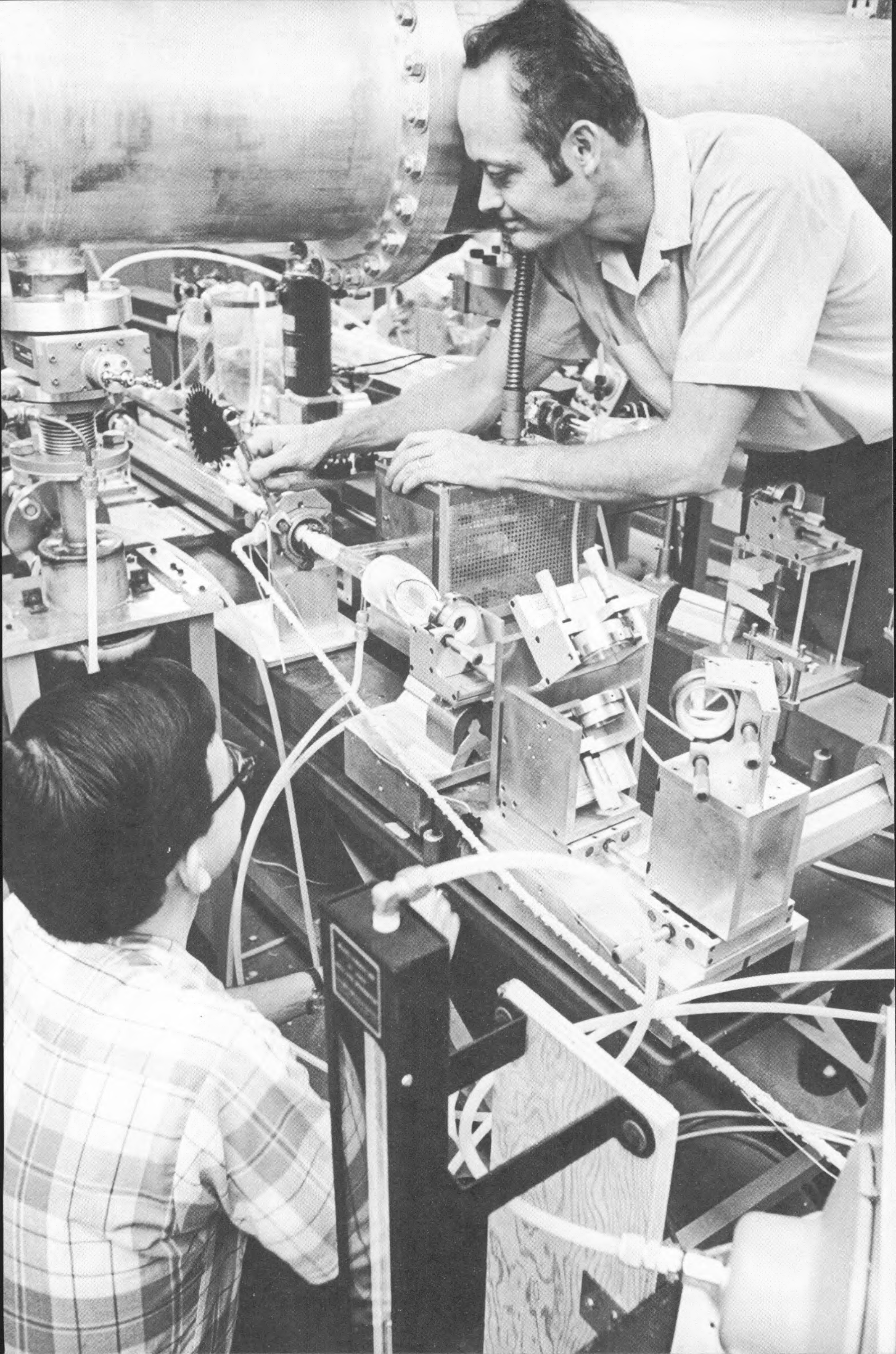
Facilities

Because of the interdepartmental and interdisciplinary nature of the Field of Applied Physics at Cornell, the available research facilities are much more extensive and unique than those generally provided by a single department.

For example, sophisticated techniques for electron microscopy and electron spectroscopy, for X-ray analysis and metallography, for special materials preparation, for chemical analysis, and for studies at very high or low pressure or very high or low temperatures are provided by the facilities of the University's Materials Science Center. Other facilities include the radar-radio observatory in Arecibo, Puerto Rico and the unique high-current relativistic electron beam facility of the Laboratory of Plasma Studies. In the Ward Laboratory of Nuclear Engineering, students can use a fast-pulsed TRIGA neutron reactor, an X-ray irradiation cell, a low-flux nuclear critical facility, and a high-current charged-particle accelerator (Dynamitron) for energies up to 3 MeV.

Areas of Research

Broad applicability is a characteristic of physical methods of analysis and measurement, and a great number of these methods are being applied in many research areas within the Field of Applied Physics. Examples of the various programs now under way are described briefly in nine general groups. The names of professors who are working with specific projects are indicated in parentheses.



Solid State Physics

Research in solid state physics is conducted over a range of specific subject areas, such as defects and physical properties, superconductivity, quantum electronics and microwaves, phase transformations, and surface physics; and many approaches, from theory to experiment, are employed. As an example, phase transformations and transport properties are studied in ferroelectrics and superconductors, on crystal surfaces, at high pressures, and within single crystals of a two-component solid. The tools for the studies include theoretical analysis, X-ray and electron diffraction, light and microwave scattering, electron spectroscopy, field ion microscopy, and ultrasonics.

Many of the research projects in the area of solid state physics involve faculty members who hold appointments in other engineering disciplines such as electrical engineering, mechanical engineering, and materials science and engineering.

A major area of interest in solid state physics is the study of imperfections and their relation to the physical properties of crystals. Crystal imperfections are studied by electron and field ion microscopy (Balluffi, Seidman), and individual ions are imaged and identified by mass spectroscopy (Seidman).

Current research in superconductivity is involved with many different solid state aspects of matter. Study of the fluctuations in superconductors is of interest because of the macroscopic quantum-coherence characteristic of the superconducting state, which limits the fluctuation process. Quantum superconductivity provides the basis for some spectacular low-temperature electronic devices, such as the fastest available computer elements at 10^{-9} sec cycle time, the most sensitive voltmeters at 10^{-16} volts, and the most sensitive magneto flux detectors at 10^{-18} Webers. Synthesis of superconducting microstructures for these devices is a crucial problem, approached here with use of electron beam pattern tracing techniques (Webb).

Other research in this general area is concerned with structure studies of phase transformations associated with high-field superconductors and with the properties of flux line lattices in Type II superconductors where pinning of the flux line by crystal defects can be very important in achieving high critical currents (Kramer). Direct electron microscopy observations of flux line lattices by surface decoration with small (40 Å) ferromagnetic particles have just been completed (Silcox).

There are many phenomena associated with the periodic or the defect properties of three-dimensional solids that are strongly influenced by the presence of surfaces and interfaces. The study of electron and atomic structure of crystal surfaces is a well-established program in solid state physics. Surface phenomena of current interest include inelastic and elastic scattering of electrons, atoms, and ions by solid metal surfaces and the development of dynamical theory of multiple scattering by electrons in the low energy range (Rhodin). The macroscopic surface properties associated with surface-thermodynamics and with transport are also under active study for ionic crystals and semiconductors (Blakely). Surface studies of gas-metal reactions by low-energy electron diffraction (Blakely and Rhodin) is also a major research area. Solid state electron spectroscopy, including photoemission, Auger emission, and field emission, is applied broadly toward an investigation of the electron properties of surfaces and fine particles with specific applications to chemisorption and catalysis (Rhodin). Electron energy loss measurements at high electron energies (75 KeV) focus on electron excitations in the energy range 1–100 eV; these include bulk plasmons, surface plasmons, and optical Cerenkov radiation (Silcox).

An active research program is underway in the area of solid state semiconductor physics. This involves quantum electronics and microwave behavior associated with harmonic emission from solid state microwave oscillators such as Gunn-effect, limited-space-charge-accumulation, and avalanche diodes (Ballantyne). The epitaxial growth of intermetallic compound crystals such as gallium arsenide and the use of these for microwave oscillators based on the transferred electron effect are also being studied (Eastman). Other projects underway involve study of epitaxial growth of silicon crystals and diffusion and sputtering processes in silicon and other semi-conductor microwave devices (Lee).

Since many important solid state properties are structure-sensitive, study of phase transformations is often an important approach to such specific phenomena as charge distribution and electron transport in solids. Phase transitions in ferroelectric crystals and their relationship to the lattice dynamics of the material are being studied with use of dielectric spectroscopy (Ballantyne). Studies of phase transformations in the solid state are pursued on many different fronts. Mössbauer diffuse scattering is used to study the dynamical aspects of lattice instabilities in alloy systems (Batterman). Also of great interest from this viewpoint is an investigation of the possibility that metallic hydrogen produced at high pressures will exhibit a superconducting transition temperature in the neighborhood of room temperature. This work involves pressure-volume measurements on solid molecular hydrogen at pressures up to 30 kilobars (Ruoff). Anharmonic and bonding properties in solids are being studied through neutron diffraction experiments which are being performed at the High Flux Beam Reactor at Brookhaven National Laboratories (Batterman).

Some recent typical publications and theses in the area of solid state physics are:

Batterman, B. W.; Maracci, G.; Merlini, A.; and Pace, S. 1973. Diffuse Mössbauer scattering applied to dynamics of phase transformations. *Physical Review Letters* 31:227.

Buhrman, R. A. 1973. The Diamagnetic Transition in a "Zero-Dimensional" Superconductor. Ph.D thesis. (Professor Webb.)

By mixing reactive gases, powerful coherent infrared radiation is produced directly in this laser without any external power source.

Demuth, J. E. 1973. Chemisorption Studies of Nickel Surfaces Utilizing Work Function Measurements, Auger, and Low Energy Diffraction Grating. Ph.D. thesis. (Professor Rhodin.)

Jackel, L. D.; Webb, W. W.; Lukens, J. E.; and Pei, S. S. 1974. Measurement of the probability distribution of thermally excited fluxoid quantum transitions. *Physical Review* (in press).

Kramer, E. J. 1973. Scaling laws for flux pinning in hard super-conductors. *Journal of Applied Physics* 44:1360.

Pacher, E. E. 1973. Small Angle Scattering Effects in Some Galvonomagnetic Coefficients of Copper. Ph.D. thesis. (Professor Silcox.)

Randles, M. H. 1973. Characterization of a Short Transit Time Avalanche Diode Oscillation. M.S. thesis. (Professor Lee.)

Rhodin, T. N. 1972. Recent approaches to atom-surface interactions. In *Proceedings of the 7th international conference on reactivity of solids*, ed. M. W. Roberts. London: Chapman & Hall.

Schwerer, F. C., and Silcox, J. 1972. Electrical resistivity due to dislocations in nickel at low temperatures. *Philosophical Magazine* 26:1105.

Seidman, D. N. 1973. Direct observation of point defects in irradiated or quenched metals by quantitative field ion microscopy. *Journal of Physics F* 3:393.

Webb, W. W. 1972. Superconducting quantum magnetometer. *Institute of Electrical and Electronic Engineers: Magnetic Transactions* 8:51.

Plasma Physics

A unified, interdisciplinary approach to plasma studies at Cornell provides the opportunity for graduate study in the area of plasma physics in combination with work in applied physics, aerospace engineering, chemistry, electrical engineering, thermal engineering, or physics. Much of the experimental and theoretical work is conducted at the interdepartmental Laboratory of Plasma Studies. Several professors within the Field of Applied Physics are actively involved in plasma research, with approximately equal attention given to experimental and theoretical aspects.

Most of the current effort at Cornell is centered on confinement and heating problems in controlled thermonuclear research. Studies of various magnetic configurations and of instabilities and waves in plasmas are underway. Investigations of turbulence induced by strong electric fields are also in progress; Cornell is recognized as the leading university in the area of high-current relativistic beam technology and its applications in thermonuclear research. In addition to controlled thermonuclear studies, research is being done on collisionless shock-waves, solar, magnetospheric, and ionospheric plasma physics, plasma turbulence, and kinetic theory.

The dynamical behavior of fully ionized plasmas is being studied with use of a plasma wind tunnel under conditions in which collective plasma effects are important but ordinary collisions between single particles are not (Auer, deBoer, Resler). These studies relate to the understanding of collision-free shock formation and the nature of the earth's bow shock in the solar wind. Earlier studies of slightly ionized continuum plasmas have led to the development of electric probes at large negative potential (deBoer). Such probes can provide information on ionization phenomena, and on the flowfield around vehicles reentering the atmosphere.

One of the most potentially useful experimental facilities in plasma studies is the high-power, fast-pulsed relativistic electron beam. At the present time two potential applications of these beams for thermonuclear fusions are being investigated. First, the magnetic field associated with the electron beam may be useful for producing magnetic-field configurations that, according to theoretical predictions, will provide stable confinement of fusion plasmas. Second, the total energy content of these beams is quite sizeable compared with plasma energies generally encountered in controlled-fusion experiments, and the beam may thus be used for heating such plasmas (Fleischmann, Kusse). In another project, the possibilities for the heating of a fusion plasma by strong turbulence effected by the electron beam is being investigated (Wharton).

Theoretical aspects of plasma problems are also being studied. Part of this effort concentrates on theoretical aspects of the mentioned applications of high-current relativistic electron beams for fusion research (Sudan). Also being considered are instabilities in space plasmas (Sudan), the interaction of microwaves with electron beams (McIsaac), shock waves in plasmas (Auer), and kinetic theories of plasmas (Liboff).

The following papers on aspects of plasma physics are among those recently published:

Andrews, M. L.; Davitian, H.; Fleischmann, H. H.; Kusse, B.; Kribel, R. E.; and Nation, J. A. 1971. Generation of astron-type E-layers using very high current electron beams. *Physical Review Letters* 27:1428.

Bzura, J. J.; Fessenden, T. J.; Fleischmann, H. H.; Phelps, D. A.; Smith, A. C., Jr.; and Woodall, D. M. 1972. Trapping of high-current relativistic electron beams in a magnetic mirror trap. *Physical Review Letters* 29:256.

deBoer, P. C. T. 1973. Ion boundary layer on a flat plate. *American Institute of Aeronautics and Astronautics Journal* 11:1012.

Ott, E., and Sudan, R. N. 1971. Finite beta equilibrium of relativistic beams in toroidal geometry. *Physics of Fluids* 14:12.

Thode, L. E., and Sudan, R. N. 1973. Two-stream instability heating of plasmas by relativistic electron beams. *Physical Review Letters* 30:732.

Quantum Optics, Laser Physics, and Nonlinear Optics

One of the more dramatic recent developments in physics is the discovery and application of the laser as a source of intense coherent radiation. Research in this field combines many aspects of optics, atomic and molecular physics, solid state physics, and chemistry. Opportunities for research in this field at Cornell include studies of light scattering, chemical and molecular lasers, tunable laser spectroscopy, linear and nonlinear optical properties of materials, and the physics of electrooptical devices. Laboratory research facilities are modern and sophisticated.

In the chemical and molecular laser field, research oriented toward the discovery and study of new laser systems is in progress. The relaxation of vibrational excitation in molecules through atomic and molecular collisions is being studied over a wide range of experimental parameters. In addition, laser-induced selective excitation of molecules is being studied as a means of selective initiation of chemical reactions under nonthermal conditions and for studies of molecular energy transfer.

Quantum optics and modern fluctuation correlation methods are being used to study the dynamics of turbulent flows, the kinetics of chemical reactions, and the statistical process as applied to superfluids. Coherent optics also find applications in a variety of biophysical experiments, including studies of the visual process, of diffusion in biological membranes, and of turbulence in flows chosen to simulate artificial blood flows.

With the availability of intense laser sources, the nonlinear optical properties of solids, liquids, and gases have become accessible to detailed experimental study. The information obtained has led to improved understanding of many such materials and to an increasing number of applications of technological importance. Optical properties and applications of such materials as III-V, II-VI, and II-IV-V_2 compounds are being studied. In the electrooptics area, materials problems related to the development of thin-film miniaturized optical components and devices are being studied.

Finally, tunable lasers from the ultraviolet to the infrared part of the spectrum are being developed, and applications to tunable laser spectroscopy are planned. This work is interdisciplinary, with joint participation of faculty members and students in the graduate Fields of Chemistry, Physics, Electrical Engineering, and Biology.

Some recent typical publications and theses in this area are:

Chou, P. T. 1971. Photon Loss in Cadmium Sulfide Electron-Beam Pumped Lasers. M.S. thesis. (Professor Ballantyne.)

Hodges, D. T., Jr. 1971. Experimental and Theoretical Studies of Rare-Gas Ion and Metal-Vapor Ion Lasers. Ph.D. thesis. (Professor Tang.)

Liu, Y. S. 1973. Experimental and Theoretical Studies of the Vibrational Energy Distribution in Carbon Monoxide Produced in the Reaction of Oxygen with Acetylene. Ph.D. thesis. (Professor McFarlane.)

Liu, Y. S.; McFarlane, R. A.; and Wolga, G. J. 1972. Totally inverted vibrational population of CO formed in the reaction of oxygen with acetylene. *Chemical Physics Letters* 14(5):559.

Rosen, D. I.; Sileo, R. N.; and Cool, T. A. 1973. A spectroscopic study of CW chemical lasers. *Journal of Quantum Electronics* QE-9:163.

Scholl, F. W., and Tang, C. L. 1973. Nonlinear optical susceptibilities of II-IV-V_2 compounds. *Physical Review B* (in press).

Stephens, R. R. 1971. Vibrational Energy Transfer Processes in the DF, HF, DF-CO_2 and FH-CO_2 Chemical Lasers. Ph.D. thesis. (Professor Cool.)

Tsuchiga, S.; Nielsen, N.; and Bauer, S. H. 1973. Lasing action and the relative populations of vibrationally excited CO produced in $CS_2 + O_2 +$ He mixtures. *Journal of Physical Chemistry* 77:2455.

Turner, J. J.; Chen, B.; Yang, L.; Ballantyne, J. M.; and Tang, C. L. 1973. Gratings for integrated optics fabricated by electron microscope. *Applied Physics Letters* 23(6):333.

Low-Energy Nuclear Physics

Research and instruction in nuclear structure and low-energy nuclear physics is conducted by staff who are members of both the graduate Field of Applied Physics and the graduate Field of Nuclear Science and Engineering. The student interested in this area can follow essentially the same program in either Field; the choice depends on the aspect he wishes to emphasize. If he wishes to concentrate his minor in engineering applications such as nuclear power, Nuclear Science and Engineering is the more appropriate Field. If his interests are more basic or are in applications of nuclear physics in other sciences such as astrophysics or geophysics, Applied Physics may be the more suitable Field. In either Field he can construct an individualized program in consultation with faculty members on his Special Committee.

The facilities for experimental research in nuclear physics are housed in the Ward Laboratory of Nuclear Engineering.

Astrophysics

Astrophysics is an area in which Cornell has gained world-wide attention over the past few years. Special efforts are directed toward studies of the lunar surface, planetary surfaces and atmospheres, infrared radiation from cosmic objects, the theory of high-energy objects such as quasars and pulsars, and radio and radar astronomy. Some of the faculty members of the Field of Applied Physics who are involved in these projects hold appointments in the

Department of Astronomy or in the School of Electrical Engineering.

In addition to extensive astrophysics laboratory facilities in Ithaca, there is available the National Astronomy and Ionosphere Center Observatory, which is operated by Cornell University at Arecibo, Puerto Rico. This facility, which has a 1,000-foot radio-radar telescope, the world's largest, has recently been upgraded to operate at much shorter wavelengths than had been possible, and so improve radar sensitivity by a factor of 2,000. This will provide exceptional research opportunities for graduate students. Some students in applied physics have started on outstanding careers through their work in astrophysics at Cornell.

Through careful observations with high signal-to-noise ratio, made at Arecibo, the characteristics of pulsars are being defined. The observations have already provided the fundamental information that neutron star matter exists in the universe and is encountered in pulsars; and that the enormous energy release from these objects comes from the braking of their spins. The measurements, made sometimes with microsecond resolution, identify complex sets of phenomena that occur within the individual pulsar pulses. In this phenomenon each pulsar has its own signature, but the underlying physics is not yet understood (Drake).

Infrared observations of regions where stars are now being formed have been conducted using a variety of new techniques. The instruments are developed at Cornell and ground-based observations are made at observatory sites in the western United States. Because the atmosphere is opaque in most of the infrared spectral range, rocket-borne telescopes have been constructed and launched to observe the sky from above the atmosphere. Besides yielding information on the infrared radiation coming from cosmic sources, rocket flights have also provided new data on the thermal structure and composition of the upper atmosphere (Harwit).

A study of very low-frequency emissions that originate in the magnetosphere includes experimental testing of a theoretical explanation of the phenomenon. The mechanism for the generation of these emissions is thought to be closely associated with a process in which high-energy electrons drive whistler waves to instability. In an experiment to verify some of the theoretical predictions, the approach is to launch circularly polarized electromagnetic waves on a plasma column and observe the interactions with an electron beam having both longitudinal and rotational energy (Sudan, Kuckes, and Wharton).

Representative of publications and theses in this area are:

Drake, F. D., and Sagan, C. 1973. Interstellar radio communication and the frequency selection problem. *Nature* 245:257.

Harwit, M.; Houck, J. R.; and Fuhrmann, K. 1969. Rocket borne liquid helium cooled telescope. *Applied Optics* 8:473.

Kuckes, A. F. 1971. Lunar electrical conductivity. *Nature* 232:249.

Niell, A. E. 1971. Flux Densities and Spectra of Extragalactic Radio Sources. Ph.D. thesis. (Professor Harwit.)

Geophysics

Cornell has an expanding program in solid earth geophysics, with emphasis on the application of the basic sciences to the solution of problems of geology. Much of the work in this area is being done by members of the Department of Geological Sciences.

A program of seismological observations in various parts of the world provides raw data for studies of earthquakes and of earth structure. Through the unifying new geological theory of plate tectonics, these studies are related to those of other disciplines and lead to a better understanding of the earth and its use (Oliver and Isacks).

A theoretical and experimental investigation of solid state mantle convection is also being carried out. The purpose of the study is to determine the structure of convection cells within the earth and to interpret their interactions with the surface in terms of the global plate tectonic theory. These studies are also being extended to the interiors of other planets and the moon (Turcotte).

Experimental studies of the electrical properties of the earth are motivated by interest in the geologic processes in the lower portions of the continental crust and by problems of earthquake prediction. Similar phenomena are being used to study the temperature of the moon's interior (Kuckes).

Among representative publications in this field are:

Kuckes, A. F., 1971. Lunar electrical conductivity profile. *Nature* 232(5308):249.

Oliver, J.; Isacks, B.; Barazangi, M.; and Mitronovas, W. 1973. Dynamics of the down-going lithosphere. *Tectonophysics* 19:133.

Turcotte, D. L., and Oxburgh, E. A. 1969. Continental drift. *Physics Today* 22(4):30.

Biophysics

The interdisciplinary field of biophysics includes the many areas in which the study of biological systems and biogenic materials may be approached using the methods and procedures of physics. The members of the faculty and staff of the Field of Applied Physics at Cornell who direct their research to biophysical problems are particularly interested in photobiology, the functional ultrastructure of cells, and the configuration and molecular structure of biogenic macromolecules. Their close collaboration with researchers in the Division of Biological Sciences and in the molecular biophysics program in the Department of Chemistry provides a wide range of opportunity for interested students. There are also projects underway which have applications in the study of biomedical engineering.

The chemistry of photosynthesis takes place in reaction centers that can be isolated from their natural environment (photosynthetic bacteria as well as green plants). The reaction centers, aside from their importance for understanding the mechanics of photosynthesis, are interesting objects for the study of molecular spectroscopy, quantum electron physics, and oxidation-reduction photochemistry. Experimental research in this area includes biochemical preparations and chemical analyses as well as physical methods of absorption-emission spectroscopy (Clayton).

Recent developments in tunable lasers are being applied to the visual process to try to elucidate the chemical reactions responsible for particular electrophysiological responses. It has been possible to study nondestructively and selectively the principal molecules of the visual process in an intact eye using tunable laser resonance Raman spectroscopy. The data obtained yield information about the structure, the environment, and the interactions of specific molecules during the visual cycle. These experiments, it is hoped, will lead to the capability of monitoring, in a living eye, the specific chemical reactions associated with the principal electrophysiological responses that are of importance in vision (Lewis).

The electrical properties of plant cell membranes are of particular interest because it is becoming clear that they are controlled by the systems responsible for active transport (ion pumps) rather than the passive movement of ions. The microelectrode techniques used in these studies are also being used to investigate the role of intercellular connections in long-distance transport (Spanswick).

Physical methods are also being used in studies of nerve cells and innervated structures, secretory cells, and developing (embryonic) cells. New methods are being developed for studying the physiology of these cells on a fine-structural level. The most important recent example is the application of quantitative electron microscope autoradiography (that is, the high-resolution detection of radioactivity inside cells) to the study of cellular function. By introducing radioactive precursors into the cell, one can localize the compartments within a cell involved in the production, storage, and transport of secretory products. Studies are also conducted on the sites of action of neurotransmitters and various enzymes involved in nerve function (Salpeter).

Investigations of the configuration and atomic structure of biogenic macromolecules are being pursued with very high-resolution electron microscopy. Nucleic acids—their configuration, association, and polymerization—and ultimately the direct observation of the base sequence in the polynucleotide are of particular interest in these studies. Observations on enzyme configurations, substructure, and active site location are also being made. An electron microscope to achieve still higher resolutions is among procedures and instrumentation being developed (Siegel).

The dynamics of biophysical processes are being studied with the help of modern physical optics. Diffusion and the chemical kinetics of membrane transport processes in model membranes and in living normal and cancer cells are being measured by analysis of the spectrum of the fluctuations of fluorescence emitted by chemical indicators. The kinetics of cooperative chemical binding by hemoglobin is also being studied by optical observation of photolysis reactions. Changes in the fluidity of cell membranes during their growth cycle are being observed by optical probing of their mechanical and rheological properties. Auditory mechanisms in insects are also under study in an attempt to understand certain aspects of the development of the nervous system. A laser technique has been developed that permits measurement of the vibration amplitude of the eardrum even below the threshold without touching it. Applications to living locusts are giving the response spectra (Webb).

Among recent publications and theses in this area are:

Clayton, R. K. 1970 and 1971. *Light and living matter,* vols. I and II. New York: McGraw Hill.

Lewis, A., and Spoonhower, J. 1973. Tunable laser resonance Raman spectroscopy in biology. In *Neutron, X-ray and laser spectroscopy in biophysics and chemistry,* ed. S. Yip and S. Chen. New York: Academic Press.

Magde, D.; Elson, E.; and Webb, W. W. 1972. Thermodynamic fluctuations in a reacting system —measurements by fluorescence correlation spectroscopy. *Physical Review Letters* 29:705.

Riddle, G. H. N. 1971. Growth and Properties of Thin Pyrolytic Graphite Films for Electron Microscopic Substrates. Ph.D. thesis. (Professor Siegel.)

Salpeter, M. M., and Salpeter, E. E. 1971. Resolution in electron microscope radioautography II Carbon-14. *Journal of Cell Biology* 50:324.

Siegel, B. M. 1971. Current and future prospects in electron microscopy for observations in biomolecular structure. *Philosophical Transactions of the Royal Society of London* B261:5.

Atomic and Molecular Physics

A precise knowledge of the processes that can occur when atoms and molecules interact by collision is of great importance in applied physics. Current projects in atomic and molecular physics are directed toward an understanding of collisionally induced processes that occur in several different physical environments. These include: (1) studies of dissociation, ionization, recombination, molecular energy transfer, and chemical kinetics in gases with thermal kinetic energies; (2) study of gas-surface phenomena, including catalysis, chemisorption, oxidation, and related phase transformations which occur at solid surfaces; (3) investigations of inelastic collision processes with nonthermal kinetic energies varying from 50 eV to several keV; and (4) studies of molecular structure with the diffraction of 50–100 keV electrons from gas-phase molecules. A partial description of current research in these areas includes the following studies.

An experimental program is in progress for the measurement of total and differential cross sections for excitation, ionization, charge transfer, and quenching processes involving neutral hydrogen and helium atoms and ions with kinetic energies from 50 eV to several keV (Fleischmann).

Experiments are being carried out on inelastic collision processes in high-temperature gases—that is, for collision energies up to a few eV. These processes include dissociation, ionization, recombination, and relaxation of vibrational and electronic excitation. Most of this work is carried out with the use of shock tubes for the preparation of the high-temperature gas. Emphasis is being given to processes of importance for environmental pollution and for gas lasers (Bauer, de Boer, and Resler). Shock tube techniques are also being applied to the study of droplet nucleation in the vapor phase of iron and other metals (Bauer).

Details of energy transfer and particle rearrangement in collisions involving vibrationally or rotationally excited molecules are being studied in view of their importance for the operation of molecular gas lasers. For this purpose, nonequilibrium distributions of molecular excitations in gases are initiated by nonchemical shocks or electrical discharges. Using various diagnostics, the kinematic evolution of these systems is investigated and the results analyzed in terms of the basic processes (Bauer). Additional studies of direct relevance to chemical and molecular gas lasers are based upon the laser-induced fluorescence technique. This technique permits the selective initiation and monitoring of specific vibrational and rotational energy transfer processes in laser molecules (Cool, McFarlane, Wolga).

The collisions of atoms, ions, and electrons with surfaces of metals and semiconductors in ultrahigh vacuum and chemically reactive environments are also being studied. The theoretical investigations are concerned with the quantum-mechanical description of the interatomic forces and charge transfer associated with the calculation of energy levels and the mobility and binding of atoms on surfaces. Experimental measurements of the parameters associated with these models are being made by low-energy electron scattering techniques and by energy-loss spectroscopy. The program is directed at formulating a general theory of absolute reaction rates for both physical and chemical processes, such as chemisorption, oxidation, and related phase transformations occuring at surfaces. (Rhodin and Blakely).

The small-angle scattering of 50–100 keV electrons by gas molecules is being investigated experimentally. From the measured diffraction pattern, structural information, particularly on bond distances between atoms, can be derived. This method is applicable to a wide variety of gases (Bauer).

High-resolution electron microscopy of biomacromolecules is an active area of research in applied physics.

Recent publications and theses in this area include:

Ahl, J. L., and Cool, T. A. 1973. Vibrational relaxation in the HF-HC1, HF-HBr, HF-HI, and HF-DF systems. *Journal of Chemical Physics* 58:5540.

Ahl, J. L.; Bauer, S. H.; and Andreassen, A. L. 1972. Reduction of diffraction data for molecules with large amplitude motions. *Journal of Physical Chemistry* 76:3099.

deBoer, P. C. T. 1970. Cross sections for energy transfer in classical coulomb collisions. *Physical Review A* 1:1631.

Dehmel, R. C.; Chau, H. V.; and Fleischmann, H. H. 1973. Experimental stripping cross sections for atoms and ions in gases, 1950–1970. *Atomic Data* 5:231.

Demuth, J. E. 1973. Chemisorption Studies of Nickel Surfaces Utilizing Work Function Measurements, Auger, and Low Energy Diffraction Grating. Ph.D. thesis. (Professor Rhodin.)

Gadzuk, J. W.; Hartman, J. K.; and Rhodin, T. N. 1971. Approach to alkali-metal chemisorption within the Anderson model. *Physical Review B* 4:241.

Statistical Physics

Statistical physics provides the theoretical connection between the detailed microscopic motions of atomic particles and the macroscopic, physically measureable quantities. Many measurable quantities can be described rigorously by evaluable functions of a small number of variables—correlation functions—which are far less detailed and specific than the microscopic state itself. Several members of the faculty in the Field of Applied Physics are concerned with developing improved techniques for determining these correlation functions and their associated macroscopic properties. An active interplay between theory and experiment is characteristic of the vitality of this area, which has so greatly increased our understanding of such varied forms of matter as liquids, gases, plasmas, superfluid helium, superconductors, and magnetic systems.

A current theoretical study of phase transactions and critical phenomena involves work in statistical mechanics, including both its applications and its rigorous mathematical formulation. Systems studied include ferro- and antiferromagnets, superfluids, binary alloys and fluids, ferroelectrics, etc., in bulk and in films. Questions in mathematics concerning spatial dimensionality, combinatorics, counting linear graphs, and special determinants and matrices arise in the course of such work (Fisher).

Experimental studies of cooperative phenomena are making use of newly devised optical correlation techniques based on modern lasers. For example, time correlation techniques have permitted analysis of inelastic scattering of visible light with an effective resolution of 10^{-16}. Modern optical techniques are applied also to investigations of critical phenomena in fluids, turbulence, homogeneous nucleation, fluctuations in quantum fields, and surface waves.

Fluctuations in superconductors and cooperative phenomena in metals at extremely low temperatures are also being investigated. Superconducting quantum interference magnetometers have been developed and applied to problems in statistical physics; an absolute thermometer that works at temperatures between 10^{-2} and 10^{-5}° K by measuring nuclear magnetization with a superconducting magnetometer, has been developed; and fluctuation induced diamagnetism above the critical temperature of superconductors has been measured and analyzed.

Also of interest are applications in biophysics and geophysics of the approaches that have been developed in chemical physics for observing cooperative phenomena (Webb).

Theoretical research is directed toward the understanding of the small-scale velocity fluctuations in fully developed hydrodynamic turbulence. This has application to the dynamics of the atmosphere, but is of primary interest for an improved basic understanding of turbulence. Striking qualitative analogies have been pointed out between the universal small-scale fluctuations in a turbulent fluid, and the universal large-scale thermal fluctuations near critical points. These analogies suggest that theoretical methods which have been highly successful in the understanding of critical phenomena have promise for a deeper theoretical understanding of turbulence. To date there is a phenomenological understanding based on models of a random cascade of energy from large to small-scale motions. The principal aim of current research is to extend these cascade models, and to derive them directly from the underlying hydrodynamic equations (Nelkin).

Turbulent flows in liquids are being measured by analyzing the time spectra of fluctuations in polarized light scattering by anisotropic particles that are partially aligned by the flows (Webb).

Some recent typical publications and theses in this area are:

Barber, M. N. 1972. Critical Phenomena in Systems of Finite Thickness. Ph.D. thesis. (Professor Fisher.)

Kim, K. 1971. Model Memory Functions in Classical Fluids. Ph.D. thesis. (Professor Nelkin.)

Nelkin, M. 1974. Turbulence, critical fluctuations and intermittency. *Physical Review A* 9: in press.

Wilson, K. G., and Fisher, M. E. 1972. Critical exponents in 3.99 dimensions. *Physical Review Letters* 28:240.

Wu, E. S., and Webb, W. W. 1973. The critical liquid-vapor interface in SF_6. *Physical Review A* 8:2065.

Faculty Members and Their Research Interests

The faculty of the graduate Field of Applied Physics includes members of a number of departments in the College of Engineering as well as other units of the University. These include Materials Science and Engineering, Aerospace Engineering, Electrical Engineering, Geological Sciences, Thermal Engineering, Chemistry, Astronomy, Mathematics, and Biological Sciences.

Dieter G. Ast, Ph.D. (Cornell): *amorphous materials and polymeric materials*

Peter L. Auer, Ph.D. (California Institute of Technology): *plasma physics*

Joseph M. Ballantyne, Ph.D. (M.I.T.): *dielectric spectroscopy; solid state physics*

Robert W. Balluffi, Sc.D. (M.I.T.): *diffusion; defects in metals*

Boris W. Batterman, Ph.D. (M.I.T.): *X-ray and neutron diffraction; solid state physics*

Simon H. Bauer, Ph.D. (Chicago): *electron diffraction and shock tube techniques; chemical lasers*

John M. Blakely, Ph.D. (Glasgow): *surface physics and chemistry*

Robert A. Buhrman, Ph.D. (Cornell): *solid-state and low-temperature physics*

K. Bingham Cady, Ph.D. (M.I.T.): *reactor physics*

David D. Clark, Ph.D. (California at Berkeley): *experimental nuclear and reactor physics*

Roderick K. Clayton, Ph.D. (California Institute of Technology): *biophysics; photosynthesis*

Terrill A. Cool, Ph.D. (California Institute of Technology): *fluid dynamics; physical chemistry*

P. C. Tobias deBoer, Jr., Ph.D. (Maryland): *fluid dynamic plasma physics*

Frank D. Drake, Ph.D. (Harvard): *studies of the radio emission from pulsars; radio and radar studies of the moon and planets*

Lester F. Eastman, Ph.D. (Cornell): *microwaves; solid state plasma*

Michael E. Fisher, Ph.D. (King's College, London): *mathematical physics; statistical mechanics; phase transitions and critical phenomena*

Hans H. Fleischmann, Dr. rer. nat. (Technische Hochschule, Munich): *plasma physics; thermonuclear fusion*

Paul L. Hartman, Ph.D. (Cornell): *optical properties of solids*

Martin O. Harwit, Ph.D. (M.I.T.): *astrophysics*

Bryan L. Isacks, Ph.D. (Columbia): *seismology; global tectonics*

Herbert H. Johnson, Ph.D. (Case): *mechanical behavior of solids*

Vaclav O. Kostroun, Ph.D. (Oregon): *low-energy nuclear and atomic physics*

Edward J. Kramer, Ph.D. (Carnegie-Mellon): *low-temperature physics; polymers*

Robert E. Kribel, Ph.D. (California at San Diego): *plasma physics*

James A. Krumhansl, Ph.D. (Cornell): *theoretical and applied physics*

Arthur F. Kuckes, Ph.D. (Harvard): *geophysics; plasma physics*

Bruce R. Kusse, Ph.D. (M.I.T.): *electron beam fusion*

Charles A. Lee, Ph.D. (Columbia): *solid state physics*

Aaron Lewis, Ph.D. (Case Western Reserve): *biophysics; laser Raman scattering*

Che-Yu Li, Ph.D. (Cornell): *surface physics; mechanical properties of materials*

Richard L. Liboff, Ph.D. (New York University): *plasma physics; statistical mechanics*

Richard V. E. Lovelace, Ph.D. (Cornell): *plasma physics theory*

Ross McFarlane, Ph.D. (McGill): *quantum electronics*

Paul R. McIsaac, Ph.D. (Michigan): *microwave electronics*

Mark S. Nelkin, Ph.D. (Cornell): *statistical physics*

Jack E. Oliver, Ph.D. (Columbia): *seismology; global tectonics*

Edward Ott, Ph.D., (Polytechnic Institute of Brooklyn): *plasma physics; electrophysics*

Edwin L. Resler, Jr., Ph.D. (Cornell): *high-temperature gas dynamics; magnetohydrodynamics*

Thor N. Rhodin, Ph.D. (Princeton): *solid state physics; physics and chemistry of solid surfaces*

Arthur L. Ruoff, Ph.D. (Utah): *high-pressure phenomena; imperfections in crystals; creep*

Miriam M. Salpeter, Ph.D. (Cornell): *biophysics*

David N. Seidman, Ph.D. (Illinois): *defects in solids*

Benjamin M. Siegel, Ph.D. (M.I.T.): *electron microscopy; surface physics; biophysics*

John Silcox, Ph.D. (Cambridge): *electron microscopy; imperfections in crystals; superconductivity; ferromagnetism*

Roger M. Spanswick, Ph.D. (Edinburgh): *biophysics; ion transport*

Ravindra N. Sudan, Ph.D. (London): *plasma physics*

Chung L. Tang, Ph.D. (Harvard): *quantum electronics*

Donald L. Turcotte, Ph.D. (California Institute of Technology): *aerospace engineering; gas dynamics; geophysics*

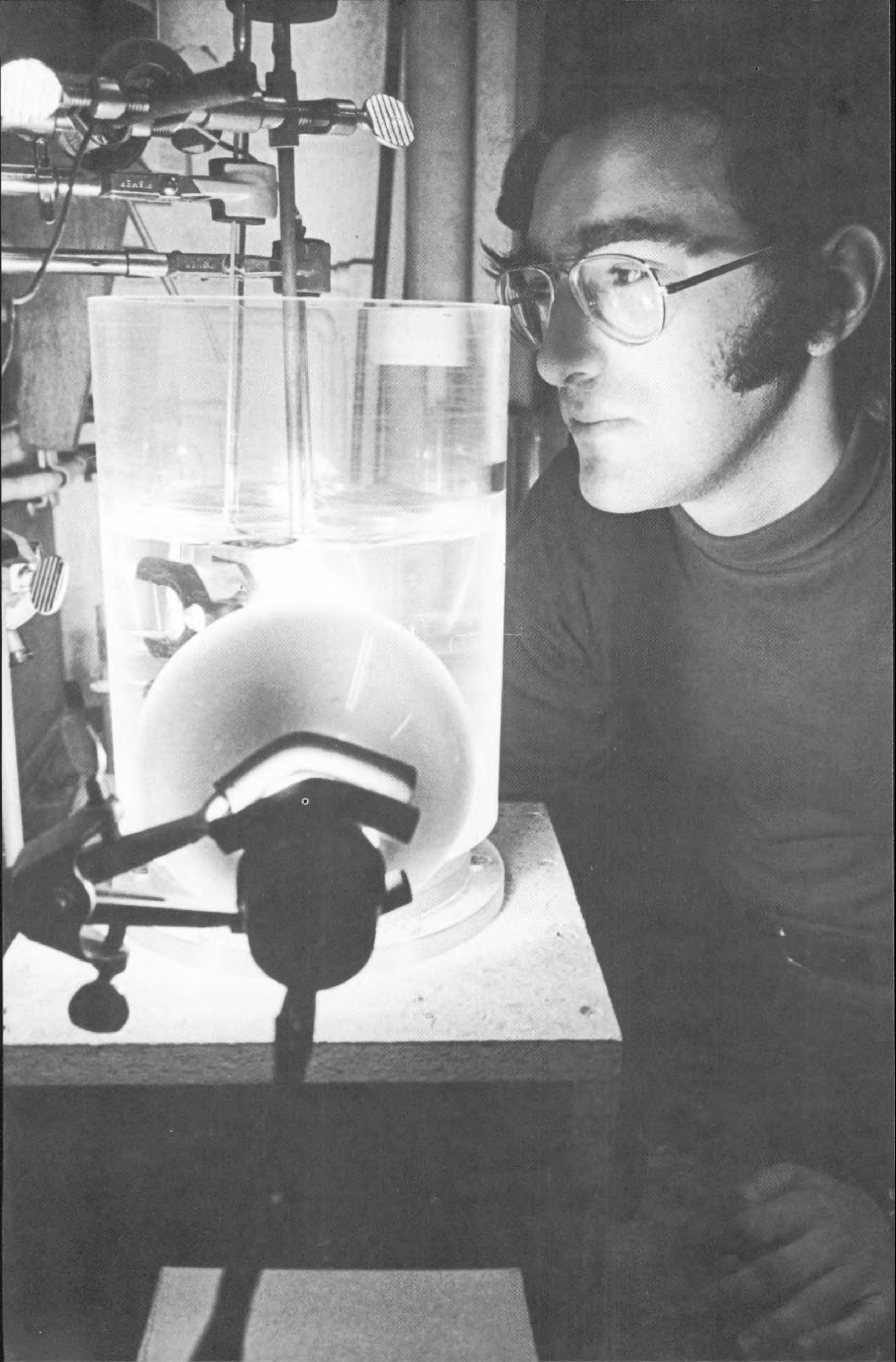
Watt W. Webb, Sc.D. (M.I.T.): *solid state physics; superconductivity; crystal mechanics; cooperative phenomena; fluids; biophysical kinetics*

Charles B. Wharton, M.S. (California at Berkeley): *plasma physics; microwave electronics*

George J. Wolga, Ph.D. (M.I.T.): *magnetic resonance; quantum electronics*

Further Information

Additional information may be obtained by writing to: Graduate Field Representative, Applied Physics, Clark Hall, Cornell University, Ithaca, New York 14850.



Chemical Engineering

The graduate Field of Chemical Engineering at Cornell offers programs in developing and interdisciplinary specialties as well as in the more traditional areas of chemical engineering. Approximately fifty students are now pursuing graduate work in a variety of areas.

As in most engineering fields at Cornell, three graduate degree programs are offered in chemical engineering. Students may enter a research-oriented course of study leading to the degree of Doctor of Philosophy or Master of Science, or may study for the professional degree of Master of Engineering (Chemical).

In addition to taking courses offered by the School of Chemical Engineering, students may elect courses offered by a number of other University schools or departments. For example, Cornell's widely recognized Department of Chemistry offers many advanced courses that are appropriate for graduate students in chemical engineering, as do the Departments of Mathematics and Physics. Courses may be taken in other engineering specialties such as applied physics, electrical engineering, industrial engineering and operations research, materials science and engineering, theoretical and applied mechanics, water resources engineering, and thermal engineering. In the biological sciences, graduate courses are available in biochemistry, biophysics, bacteriology, physiology, and nutrition. Some graduate students in chemical engineering select minors in such nonengineering fields as law, business administration, or economics.

Facilities

Study and research in chemical engineering is carried out in Olin Hall of Chemical Engineering, a modern, well-equipped building. It includes many small laboratories for graduate student research, and also houses such specialized laboratories as the Geer Laboratory for Rubber and Plastics, the extensive unit operations laboratory, and others for biochemical engineering, microscopy, process development, transport phenomena, and kinetics. The School maintains its own library of reference books and periodicals to supplement the larger libraries in the College of Engineering and the University.

Facilities of special interest in certain areas are described under the various areas of research.

In a chemical engineering graduate research project, hollow-fiber membranes which have been developed for possible use in kidney machines are tested for permeability.

Areas of Research

Transport phenomena, reaction kinetics, and thermodynamics are the fundamentals of chemical engineering, and projects in these areas are an important part of the total research activity of the University. A special area of research is process synthesis and economics. Candidates for the M.S. and Ph.D. degrees may work on thesis problems related to the expanding product interests of the chemical industry. The extension of chemical engineering techniques to the fields of biology and medicine, desalination, polymers, and high-energy radiation has been a natural outgrowth of the diverse staff research interests, and all of these areas of research are available to graduate students.

Most of the School's current research activities can be grouped into the categories listed below, although there is considerable interaction among these areas—for example, there may be studies of the effects of radiation on polymeric properties—and the groupings are necessarily arbitrary.

Biochemical Engineering

Chemical engineers are challenged to consider the mass production of living cells and the economical isolation of both cells and cell products such as antibiotics and enzymes. Not only the production of useful chemicals, but also the development of future procedures for waste treatment, protein manufacture, serum production, and plant tissue culture depends on biochemical engineering.

The research of Professor Finn is concerned with application of semipure cultures to the treatment of industrial and toxic wastes, an undertaking which involves fundamental studies of the kinetics of microbial growth and product formation, and enzyme purification by solvent precipitation. There is particular interest in single-carbon metabolism, ranging all the way from cyanide disposal to biopolymer synthesis from methanol.

Professor Shuler's current research concerns experimental studies of environmental interaction with nitrogen-fixing bacteria, with particular reference to mutualism in the leaching of mineral ores and pollution of mine waste waters. He also has an interest in theoretical work on the kinetics of insolubilized enzymes. The separation of proteins, viruses, and small colloids by new methods which utilize variations in size, shape, and charge, are being investigated by Professor Anderson. Professor Rodriguez, whose major field of interest is polymers, is conducting research on the biodegradability of polymers.

Special equipment for research projects in biochemical engineering is housed in several bench-top laboratories (some with controlled temperature) and a 40-liter stainless steel pilot unit. An electron microscope and a variety of optical and analytical instruments are available.

Students majoring in biochemical engineering may minor in biochemistry or microbiology, which are offered by the Division of Biological Sciences; in nutrition and food science through the Graduate School of Nutrition; in physical biology, physiology, or pharmacology through the School of Veterinary Medicine; or in other engineering areas such as water resources or electrical engineering.

Typical recent graduate theses and publications of faculty members in biochemical engineering are:

Dabes, J. N.; Finn, R. K.; and Wilke, C. R. 1974. Equations of substrate-limited growth: The case for Blackman kinetics. *Biotechnology and Bioengineering* (in press).

Fields, R. D. 1973. Microbial Degradation of Polyesters. Ph.D. thesis. (Professor Rodriguez.)

Finn, R. K., and Tannahill, A. L. 1973. The "azotopure" process for treating nitrogen-deficient aqueous wastes. *Biotechnology and Bioengineering* 15:413.

Shuler, M. L.; Aris, R.; and Tsuchiya, H.M. 1972. Diffusive and electrostatic effects with insolubilized enzymes. *Journal of Theoretical Biology* 35:67.

Biomedical Engineering

Research in biomedical engineering involves the application of chemical engineering fundamentals to problems of medical interest. Most research projects involve close cooperation with physicians at the Cornell Medical Center, staff members at the National Institutes of Health, or both.

Professor Bischoff's current research is on mathematical modeling of drug and environmental toxicant distribution and effects in the body. Some specific results of this work are leading to optimal drug dosage regimens for cancer chemotherapy.

In conjunction with the Cornell Medical Center, several faculty members are studying the properties and medical applications of collagen, which is the basic constituent of supporting tissue in animals.

Professor Rodriguez is studying the cross-linking of collagen and collagen-polymer mixtures by ultraviolet irradiation. This research is directed toward finding collagen-based materials which will have physical properties suitable for such uses as artificial blood vessels, burn coverings, and cornea replacements. Another way in which polymers which swell or dissolve in water are useful is in the formation of complexes with small molecules such as pilocarpine or phenobarbitol; studies of this kind of binding have potential applications in detoxification and controlled-release medication.

An electron microscope and freeze-etching techniques for specimen preparation are used by Professor Cocks and his students in research on collagen gels prepared by gamma irradiation and on surface changes in collagen films before and after exposure to the body. The latter studies indicate the sequence of events which occur on an implanted collagen surface.

Professor Stevenson is investigating the mass-transfer properties of collagen hollow-fiber membranes and gels by conducting unsteady-state mass-transfer experiments. Applications of this research are the testing of hollow-fiber membranes for use in the artificial kidney and the evaluation of collagen gels for use in drug-delivery devices.

Typical recent faculty papers and graduate student theses in this area are:

Hamed, G. 1973. A Study of the Dynamic Mechanical Properties of Ultraviolet Light-Irradiated Collagen and Collagen-Polymer Gels. M.S. thesis. (Professor Rodriguez.)

Himmelstein, K. J., and Bischoff, K. B. 1973. Mathematical representation of cancer chemotherapy effects. Models of ARA-C chemotherapy of L-1210 leukemia in mice. *Journal of Pharmacokinetics and Biopharmaceutics* 1:51, 69.

Stevenson, J. F. 1973. Permeability Measurements for Hollow Fiber Membranes. Paper read at 66th Annual Meeting of the American Institute of Chemical Engineers, 11–15 November 1973, in Philadelphia, Pennsylvania.

Chemical Engineering Fundamentals

Improvement of design in the process industries is dependent on new knowledge in the areas of chemical engineering fundamentals, and research in these areas therefore constitutes a large part of the total research program in the Field of Chemical Engineering. Most faculty members supervise thesis work in this area, often as a supplement to studies in their other fields of specialization.

Fluid mechanics studies directed by Professor Scheele are concerned with the hydrodynamic stability of liquid jets and natural convection distorted flow-fields in pipes; drop formation and coalescence; and the characteristics of stirred tanks. Heat transfer work centering on non-Newtonian flow studies is being conducted by Professors Smith and Scheele. Professor Anderson is currently supervising research in the theory and measurement of neighbor interactions in diffusion of macromolecules. Professor Von Berg is investigating simultaneous mass and heat transfer in liquid-liquid extractors.

A research area receiving current emphasis is membrane diffusion. Restricted transport of large molecules in submicron pores is being studied by Professor Anderson. The experimental aspects of the research involve the use of model track-etched membranes which possess extremely uniform pore characteristics. Electrokinetic phenomena (ion exclusion, electroosmosis, etc.) arising from the presence of the double layer in these small pores are also under investigation. Professor Harriott is studying membrane permeability, with particular emphasis on ultrafiltration and reverse osmosis membranes for desalination, and Professor Stevenson is investigating the permeability of hollow fiber dialysis membranes for artificial kidneys.

Among recent faculty publications and student theses in this area are:

Anderson, J. L. 1973. The concentration dependence on marco-molecular diffusion. *Industrial and Engineering Chemistry Fundamentals,* 12:488.

Anderson, J. L., and Quinn, J. A. 1973. Restricted transport in small pores: A model for steric exclusion and hindered particle motion. *Biophysical Journal,* in press.

Beissinger, R. L. 1973. Ultrafiltration of Macromolecular Solutions. M.S. thesis. (Professor Harriott.)

Klunker, F., and Harriott, P. 1972. The permeability of membranes filled with silica gel. *Chemical Engineering Progress Symposium Series* 68(124):340.

Scheele, G. F., and Leng, D. E. 1971. An experimental study of factors which promote coalescence of two colliding drops suspended in water. *Chemical Engineering Science* 26:1867.

Yu, H. 1972. Laminar Jet Contraction and Velocity Distribution in Immiscible Newtonian Liquid-Liquid Systems. Ph.D. thesis. (Professor Scheele.)

Chemical Microscopy

Chemical microscopy has been taught at Cornell since the turn of the century, and is still a vital, growing field of study. In recent years, many new and exciting microscopes have been developed, and these have been widely used in chemical and chemical engineering research. Today, microscopical techniques are so far developed that one of the ultimate goals of chemical microscopy—to see individual atoms and molecules and to observe the reactions between them—may soon be realized.

Current research programs include studies of the formation, microstructure, and physical properties of gels and other polymeric materials. This research has potential applications in medicine. Much of the current effort is devoted to studying collagen as a biomaterial that would be useful, for example, in kidney machines, or for artificial blood vessels, sutures, corneal replacement, vitreous body replacement, or drug-delivery systems. Another aspect of microscopical research is the study of the nucleation and growth of crystals. This research has applications in such areas as desalination by freezing, the engineering production of crystalline products, mineralogy, and biomedical problems such as the growth of bones, teeth, and kidney stones. Still another group of research projects is devoted to studies of the structure of biological cells such as bacteria and yeasts.

These projects, directed by Professors Cocks, Finn, and Rodriguez, utilize the facilities of the microscopy laboratory, which is well equipped with light and electron microscopes and auxiliary equipment for the preparation of specimens.

Recent theses include:

Cluthe, C. E. 1972. A Microscopical Study of the Structure of Radiation Crosslinked Aqueous Poly-(ethyleneoxide) Gels and Frozen Cryoprotective Solutions. Ph.D. thesis. (Professor Cocks.)

Mukaddam, W. A. 1971. A Study of Secondary Nucleation of Ice. M.S. thesis. (Professor Cocks.)

Desalination

One important aspect of the total problem of providing potable water is that of purifying sea water. Cornell University was chosen by the United States Office of Saline Water as a site for studying desalination by freezing, a process that utilizes secondary, immiscible, direct-contact refrigerants. This process has favorable thermodynamics and offers intriguing engineering possibilities.

The scope of studies related to the desalination project is quite broad. For example, heat transfer research is required for study of the cooling of brine feed, a process that utilizes direct vaporization of the refrigerant which then condenses by direct contact with the cold product water and spent brine. Crystallization by refrigerant evaporation is being studied in slurry crystallizers and spray freezers; these investigations involve experimental work on nucleation, crystal-growth kinetics, agglomeration, and the washing characteristics of beds of these crystals. The washing of the crystals is done in a moving piston-bed; design studies using electrical analogs permit better evaluation of new piston-bed wash column techniques. The dynamic behavior of three-phase flow through a porous bed of nonuniform structure is studied in terms of heat transfer experimentation on the melting of the salt-free crystals by direct contact with butane vapor. Overall engineering and economic evaluations are used to incorporate the results of this experimental work at Cornell and the contributions of experimenters outside the University into the total desalination program.

Professors Cocks, Harriott, Von Berg, and Wiegandt are involved in this work, some of which is done in conjunction with the Cornell Water Resources and Marine Sciences Center. Professor Harriott is also conducting membrane diffusion studies associated with desalination by reverse osmosis.

Among recent publications and theses are:

Dabby, S. S. 1973. Ice-Brine Separation in a Bed of Aggregates of Fine Ice Crystals. Ph.D. thesis. (Professor Harriott.)

Jones, D. B. 1973. Condensation of Butane in a Gravity-Drained Ice Bed. M.S. thesis. (Professor Von Berg.)

Michelsen, D., and Harriott, P. 1970. The transport of NaCl and water through compressed hydrophilic films. *Applied Polymer Symposia* 13:27.


MATHESON
HYDROGEN

Wiegandt, H. F.; Von Berg, R. L.; and Leinroth, J. P. 1972. The piston bed and its design. *Industrial and Engineering Chemistry Process Design and Development* 11:404.

Kinetics and Catalysis

Although kinetics has been a vital part of chemical engineering instruction and research for several years, kinetic data are often the weakest link in the assessment of a new process.

At Cornell, many members of the chemical engineering staff have supervised kinetics research in which the chemistry of the reactions has usually been of prime interest. Professor Harriott is currently studying the effect of consecutive or parallel reactions on the yield of desired product in partial oxidation and liquid phase alkylation processes. He is also investigating the structure of solid catalysts and their influence on the rate and selectivity of hydrogenation and oxidation reactions. One important result of the latter work has been a better understanding of ruthenium-based catalytic converters which have been proposed for automobile exhaust emission control.

Polymerization kinetics is being studied by both Professor Rodriguez and Professor Harriott. Recent work has emphasized the mechanisms of free radical polymerization, radiation-induced reactions, and emulsion polymerization. Professor Bischoff is concerned with the kinetics of catalyst deactivation and with the analysis and design of trickle-bed reactors.

A laboratory for instruction in kinetics has been established through a grant from the National Science Foundation. This laboratory houses reactors of several types, equipped with a variety of analytical equipment. A B.E.T. apparatus and an electron microscope for use in characterizing catalysts are available in the laboratory, and NMR and X-ray diffraction equipment is available in other departments of the College.

Recent publications and theses in this area include:

Harriott, P. 1971. Kinetics of vinyl acetate emulsion polymerization. *Journal of Polymer Science* A-19:1153.

Matson, S. L. 1974. Kinetics of Ruthenium-Catalyzed Reduction of Nitric Oxide by Hydrogen. M.S. thesis. (Professor Harriott.)

Pasquali, R. E. 1972. A Kinetic Study of the Free Radical Copolymerization of Maleic Anhydride and Ethyl Vinyl Ether using the Rotating Sector Technique. Ph.D. thesis. (Professor Rodriguez.)

Wu, J. C. 1973. Effect of Crystallite Size on the Activity and Selectivity of Silver Catalysts. Ph.D. thesis. (Professor Harriott.)

Nuclear Engineering

Electric power generation by nuclear reactors is a large and expanding industry and chemical engineers with a background in nuclear physics are uniquely qualified to handle many of the problems of this industry. The refining of uranium and other fuel materials, the reprocessing of spent fuels, and the handling of radioactive waste materials are almost entirely chemical processes. Preparation for such work would require a major in chemical engineering and certain courses offered by the School of Applied and Engineering Physics, which has outstanding experimental facilities in this field. The thesis topic would probably be an application of chemical engineering to a nuclear problem. Ph.D. candidates may also work on thesis problems at the Brookhaven National Laboratory in Long Island.

Another aspect of nuclear energy is the use of high-energy radiation to induce chemical reactions, polymerization of monomers, and changes in the properties of materials. An extremely versatile gamma radiation cell is available for this work. Professors Von Berg and Rodriguez have directed several theses in this area of research.

Faculty publications and theses in this area include:

Ashline, R. C., and Von Berg, R. L. 1969. The aqueous phase oxidation of cyclohexane using gamma radiation. *AIChE Journal* 15:387.

Kiran, E. 1971. The Crosslinking of Aqueous Polymer Solutions by Gamma Radiation. M.S. thesis. (Professor Rodriguez.)

Polymeric Materials

Polymer studies center on mechanical, electrical, and optical properties of multicomponent polymer systems, including copolymers, polymer blends, filled polymers, crosslinked polymers, and polymer solutions. Also being studied are the kinetic relationships of polymerization processes, which are often rapid reactions of free-radical or ionic character, and the distribution of reaction products.

Current research on polymer rheology includes investigations of polymer melts in elongational flows and of polymer solutions and suspensions in shear flow. Although not well understood, elongational flows are encountered in such common industrial processes as film blowing, blow molding, and fiber spinning.

The Geer Laboratory for Rubber and Plastics in Olin Hall contains much equipment that is useful in polymer studies. This equipment includes infrared and ultraviolet spectrophotometers, an electron microscope, an Instron testing machine and capillary rheometer, a recording torsional pendulum, a gel permeation chromatograph, an automatic membrane osmometer, a Brabender Plasticorder, mixing devices (roll mill, Banbury mill), a BioSonic ultrasonic generator, and various other specialized equipment. For studies of various elongational flows, an apparatus has been constructed to strain polymer melts at a nearly constant elongation rate. The gamma radiation cell in the Ward Laboratory of Nuclear Engineering is also used in polymer work.

Research in this area is directed by Professors Cocks, Rodriguez, Stevenson, Thorpe, and Winding, of the School of Chemical Engineering. Work may also be done with Professor Edward J. Kramer of the Department of Materials Science and Engineering,

Graduate students are using differential flow reactors to study the influence of catalyst structure on the rate and selectivity of chemical reactions.


ELECTROMETER

who studies the mechanical behavior of crystalline polymers, and with Professor Harold A. Scheraga of the Department of Chemistry, who heads a large research group which studies protein chemistry. Polymer research is also pursued in the graduate Field of Biochemistry.

Among recent publications in this area of research are:

Kiran, E., and Rodriguez, F. 1973. Effects of gamma radiation on aqueous polymer solutions—a comparative study. *Journal of Macromolecular Science—Physics* B7:209.

Ramakrishnan, B. C., and Rodriguez, F. 1973. Drag reduction in nonaqueous liquids. *AIChE Symposium Series*, No. 130, 69:52.

Stevenson, J. F. 1972. Elongational flow of polymer melts. *AIChE Journal* 18:540.

Process Systems and Economics

Technical and economic evaluations have been a long-standing interest of the Cornell chemical engineering faculty. These include market research, process development and design, plant layout, plant siting, systems optimizations, cost estimates, and profitability analyses. Increasing attention is being focused on long-term trends and socioeconomic impacts of proposed developments. A new area of concern is energy production, with emphasis on nuclear power generation, fuel reprocessing and waste disposal, and the development of alternate fuel sources such as coal liquefaction and gasification.

Two specific research projects which have received considerable attention are the development of molecular sieve adsorption processes for separating normal paraffins and the development of a freezing process for desalination of sea water. The freezing process is discussed more fully in the section on desalination.

A comprehensive economic evaluation is a major component of a Master of Engineering (Chemical) design project. The M.Eng. degree program is described in more detail in the *Announcement of the College of Engineering.*

Professors Hedrick, Smith, Wiegandt, and York supervise research and instruction in this area. Supplementary courses are offered by the Department of Computer Science, the Department of Operations Research, and the Graduate School of Business Administration.

Typical papers and theses in this field are:

Naldi, L. J. 1973. A Survey of Marketing Costs Within the Chemical Industry. M.S. thesis. (Professor Hedrick.)

Weaver, S. D. 1969. The Adsorption of Straight Chain Hydrocarbons from Binary Liquid Solutions by (5Å) Molecular Sieve Crystals and Composite Pellets. Ph.D. thesis. (Professor York.)

A graduate research project in chemical engineering is the study of restricted transport of large molecules in submicron pores as a means of separating proteins and viruses.

Faculty Members and Their Research Interests

John L. Anderson, Ph.D. (Illinois): *membrane transport; interfacial effects on mass and charge transfer; biological separations*

Kenneth B. Bischoff, Ph.D. (Illinois Institute of Technology): *medical and microbiological bioengineering; chemical reaction engineering*

George G. Cocks, Ph.D. (Cornell): *light and electron microscopy; properties of materials; solid-state chemistry; crystallography*

Robert K. Finn, Ph.D. (Minnesota): *waste treatment; agitation and aeration; microbial kinetics; enzyme purification*

Peter Harriott, Ph.D. (M.I.T.): *kinetics and catalysis; process control; diffusion in membranes and porous solids*

J. Eldred Hedrick, Ph.D. (Iowa): *economic analyses and forecasts; new ventures development*

Ferdinand Rodriguez, Ph.D. (Cornell): *polymerization; properties of polymer systems*

George F. Scheele, Ph.D. (Illinois): *hydrodynamic stability; coalescence; fluid mechanics of liquid drops and jets*

Michael L. Shuler, Ph.D. (Minnesota): *biochemical engineering; enzyme kinetics; mixed-population dynamics*

Julian C. Smith, Chem. E. (Cornell): *conductive transfer processes; heat transfer; mixing; mechanical separations*

James F. Stevenson, Ph.D. (Wisconsin): *transport phenomena; rheology*

Raymond G. Thorpe, M. Chem. E. (Cornell): *phase equilibria; fluid flow; kinetics of polymerization*

Robert L. Von Berg, Sc.D. (M.I.T.): *liquid-liquid extraction; reaction kinetics; effect of radiation on chemical reactions; saline-water conversion*

Herbert F. Wiegandt, Ph.D. (Purdue): *crystallization; petroleum processing; saline-water conversion; direct contact heat transfer*

Charles C. Winding, Ph.D. (Minnesota): *degradation of polymers; polymer compounding; filler-polymer systems; differential thermal analysis*

Robert York, Sc.D. (M.I.T.): *molecular sieves; chemical market analyses; chemical economics; process development, design, and evaluation*

Further Information

Prospective candidates for graduate degrees in chemical engineering may obtain further information by writing to: Graduate Field Representative, Olin Hall of Chemical Engineering, Cornell University, Ithaca, New York 14850.

Civil and Environmental Engineering

Civil and Environmental Engineering deals primarily with the large fixed works, systems, and facilities that are basic to community living, industry, and commerce and vital to man's well-being. The planning, design, construction, and operation of transportation systems, bridges, buildings, water and sewage treatment facilities, dams, and other major artifacts of society are civil and environmental engineering activities. Civil and environmental engineers are major contributors to the solution of problems of urbanization, city planning, and environmental quality control. A burgeoning national population and the desire of people to cluster in metropolitan complexes require a great increase in the number of engineers who can meet the basic needs of society with efficiency, economy, and safety.

The wide range of subjects which are the concerns of civil and environmental engineers are generally grouped into a number of subfields and specializations. At Cornell, there are two subject departments in Civil and Environmental Engineering —structural engineering and environmental engineering.

More than one hundred students are now enrolled in graduate programs at Cornell civil and environmental engineering. These programs lead to the degrees of Doctor of Philosophy, Master of Science, and Master of Engineering (Civil). Major subject areas for Ph.D. and M.S. candidates are aerial photographic studies (M.S. only), environmental systems engineering, geodetic and photogrammetric engineering, geotechnical engineering, hydraulics and hydrology, sanitary engineering, structural engineering, structural mechanics (minor only), transportation engineering, and water resource systems (Ph.D. only). Minor subjects may be in these areas, in other branches of engineering, or in mathematics, physics, chemistry, or computer science. In the M.Eng. (Civil) degree program, emphasis is on design and design-oriented courses.

Modeling is an important part of modern engineering methods for the design and testing of large structures.

Facilities

A large volume of research, sponsored by government agencies and industry, is carried out in three large and fully equipped structural laboratories. The structural testing facility in Thurston Hall is one of the largest and best equipped in any university. The main test bay is a three-dimensional space frame permitting heavy loads to be applied in any direction to large structural assemblages. Major equipment items include large capacity testing machines, portable static and dynamic loading devices, and automatic data-acquisition systems. A separate concrete materials laboratory, also in Thurston Hall, is equipped for all types of basic and applied research in concrete. The structural models laboratory is among the most active and best equipped for both research and instructional modeling.

The environmental engineering facilities include controlled-temperature rooms, laboratories for course work and research in specialized areas such as biological oxidation kinetics and aquatic chemistry, and rooms specially equipped for bench and pilot-level unit process studies in biological treatment, carbon adsorption, ion exchange, electrodiaylsis, and reverse osmosis.

In the photogrammetric area, facilities include some of the latest geodetic and photogrammetric instruments and equipment. Opportunities are provided to conduct research on instrumentation for ground, aerial, and space surveys, geodetic control, analytic aerotriangulation, geometric aspects of various remote sensors, and problems inherent in land surveying. Airphotos and remote sensing facilities available in the School include an extensive library of more than 600,000 airphotos of the United States and other areas of the world. These illustrate various geographic and geomorphic features and sequential changes; many are accompanied by pertinent ground and laboratory data and other source material.

The soil mechanics laboratories contain a wide variety of both standard and specialized soil-testing equipment. Excellent facilities for the testing of stabilized soils and asphaltic mixtures are provided.

The hydraulics laboratory is equipped for demonstrations in wave mechanics and rotating flows and for a variety of conventional experiments. A large wind tunnel is available for the modeling of atmospheric transfer phenomena, important in studies of hydrology and air pollution.

Research in environmental law is greatly facilitated by the accessibility of the Cornell Law School library, which is across the street from Hollister Hall, the main facility of the School of Civil and Environmental Engineering.

A remote access terminal of the University's central computer system is located within Hollister Hall.

Areas of Research

Aerial Photographic Studies and Remote Sensing

On the basis of the interests and experience of faculty members and the facilities available at the School, graduate programs have been directed to the following areas: (1) investigation and refinement of methods of interpretation of airphotos and imageries; (2) specific applications in engineering, geology, agriculture, and planning; (3) specific applications in various climatic regions, including arctic, subarctic, and tropical areas; and (4) incorporation of airphoto and sensing data into systems for the inventory of resources of large geographical areas. Opportunities for graduate studies in cooperation with various other units of the University are excellent and encouraged.

Representative of faculty publications in this area are:

Belcher, D. J. 1971. Computer mapping—a system for better environmental planning. In *Proceedings of the symposium on land use planning.* Madison: University of Wisconsin.

Liang, T. 1974 (forthcoming). Airphoto interpretation. Chapter in *Remote sensing manual,* ed. R. Reeves et al., Washington, D.C.: American Society of Photogrammetry.

The participation of graduate students in current research projects is reflected in the following list of recent theses and projects:

Erb, T. 1974. Remote Sensing in Detecting Sensitive Clays in the Northeastern United States. M.S. thesis. (Professor Liang.)

Krieger, J. 1973. Feasibility of Detecting and Delineating Pre-Glacial Buried Channels. M.Eng. Project. (Professor Liang.)

Thung, H. 1972. An Evaluation of the Impact of a Highway on Rural Development in Thailand by Aerial Photographic Methods. Ph.D. thesis. (Professor Belcher.)

Environmental Systems Engineering

This area of study is primarily concerned with public policy planning and analysis in areas such as environmental quality management, public health, urban planning, and technology assessment. The approach that is emphasized is the use of mathematical modeling techniques for defining and evaluating alternative solutions to public sector problems. Faculty members from other departments and interdisciplinary centers at Cornell participate in the graduate program in environmental systems engineering.

Current research projects cover a wide range of topics, including agricultural pest management, epidemiology, control of infectious diseases, methodologies for assessing environmental impacts and effects, urban noise, water quality management, and solid waste control.

Representative of recent publications by members of the faculty are the following:

Bereano, P. L. 1974 (forthcoming). Courts as institutions for assessing technology. In *Scientists in the legal system*, ed. W. A. Thomas. Ann Arbor, Michigan: Ann Arbor Science Publishers.

Fisher, G. P. (with Ittig, P., and Welker, F.) 1970. *Efficiency of multimodal transport with emphasis on intermodal transfer.* Research report 7004, Department of Environmental Systems Engineering, Cornell University.

Lynn, W. R. 1973. *Evaluation of environmental health programmes*—report of a WHO scientific group. W. R. Lynn, chairman. World Health Organization Technical Report Series no. 528. Geneva.

Schuler, R. E. 1974 (forthcoming). The interaction between local government and urban residential location. *American Economic Review.*

Shoemaker, C. 1973. Optimization of agricultural pest management. II. Formulation of a control model. *Mathematical Biosciences* 17:357.

Stidham, S. (with Prabhu, N. U.) 1973. Optimal control of queuing systems. In *Proceedings of conference on mathematical methods in queuing theory.* Kalamazoo, Michigan: Western Michigan University.

Taylor, H. M. (with Costello, W. G.) 1973. Deterministic population growth models. *American Mathematical Monthly* 78:841.

Some of the recent theses written by graduate students specializing in environmental systems engineering are:

Aste-Tonsmann, J. 1973. Scheduling and Programming the Sugar Cane Crops in Peru. Ph.D. thesis. (Professor Lynn.)

Barrer, P. 1971. A Disposal Cost Schedule for Junked Automobiles. M.S. thesis. (Professor Lynn.)

Lawrence, C. 1971. An Analysis of the Allocation of the Resources of Birth Control Programs. Ph.D. thesis. (Professor Lynn.)

Scherer, C. 1973. Estimating Return to Scale in Thermal Electric Power Systems. Ph.D. thesis. (Professor Loucks.)

Swain, R. 1971. A Decomposition Algorithm for a Class of Facility Location Problems. Ph.D. thesis. (Professor Fisher.)

Geodetic and Photogrammetric Engineering

Cornell offers an integrated program of research and instruction in geodetic and photogrammetric engineering coupled with remote sensing, photographic interpretation, and cadastral engineering. The purpose of this program is to provide graduate training for civil engineers, land planners, conservationists, geologists, foresters, geographers, and others who require surveys and inventory of cultural and earth resources and must be able to present information from such inventories in the form of maps, diagrams, and displays of one, two, three, and four dimensions. Support for work in this field is provided by University resources in related areas such as geology, land planning, natural resources, theoretical and applied mechanics, electrical engineering, and agricultural engineering.

An example of recent publications based on research in this area is:

McNair, A. J. 1971. *Colorado land use and environmental resources inventory (CLARI project)—computerized inventory of 100,000 square miles in 220 classifications.* Publication of the Office of John Love, Governor of the State of Colorado, and the Department of Natural Resources.

Representative theses are:

Biggerstaff, A. C. 1972. A Photogrammetric System for Recording Historic Structures. Ph.D. thesis. (Professor McNair.)

Ealum, R. L. 1971. Earth's Gravity Field Representation by Point Mass Set. Ph.D. thesis. (Professor McNair.)

Paul, C. K. 1970. Attitude Control, Trajectory Analyses and Science Objectives of a Jupiter Orbiting Spacecraft. Ph.D. thesis. (Professor McNair.)

Geotechnical Engineering

Graduate instruction in geotechnical engineering includes courses in several specialties. In the area of soil mechanics, there are courses in engineering properties of soils, soil dynamics, foundation engineering, and earth gravity structures. A coordinated program in highway engineering and materials is offered in cooperation with the Field of Agricultural Engineering. Most students with a major interest in geotechnical engineering take courses in airphoto interpretation and geological sciences.

Research activities can be grouped into three major areas: soil behavior, soil-structure interaction, and probabilistic approaches to geotechnical engineering design. Research projects are also carried on jointly or in cooperation with others in the Cornell community, particularly faculty members who are specialists in remote sensing and in highway materials and engineering.

The following representative publications by faculty members and associates indicate some of the current research activity in this area:

Kay, J. N., and Krizek, R. J. 1971. Estimation of the mean for soil properties. In *Proceedings of the first international conference on applications of statistics and probability to soil and structural engineering*, p. 279. Hong Kong: Hong Kong University Press.

Sangrey, D. A. 1972. Naturally cemented sensitive soils. *Geotechnique* 22(1):139.

Some recent thesis work by graduate students in this field is:

D'Andrea, R. 1974. Probabilistic Approaches to Geotechnical Engineering. Ph.D. thesis. (Professor Sangrey.)

Sparacin, W. 1974. Settlement and Stability of Structural Foundations Under Large Live Loading. Ph.D. thesis. (Professor Sangrey.)

Hydraulics and Hydrology

At Cornell, hydraulics and hydrology is oriented toward a study of the fluid earth, water on earth, and the near atmosphere. Instruction progresses from basic fluid mechanics to courses oriented toward specific applications. Effects of man's works on the environment are included, as well as studies which lead to a better understanding of natural processes.

Recent research projects by faculty members and graduate students have included studies of lake circulation and of unsteady flows in channels. Hydrologic research has included several projects on evaporation from water and land surfaces and on ground-water flow and the fluid mechanics of porous materials.

A sampling of recent and current research projects in hydraulics and hydrology is given in the following list of faculty publications:

Brutsaert, W. 1973. *Heat and water vapor exchange between water surface and atmosphere.* Report EPA-R2-73-259, Office of Research and Monitoring, U.S. Environmental Protection Agency.

Gallagher, R. H.; Liggett, J. A.; and Chan, S. T. K. 1973. Finite element shallow lake circulation analysis. *Journal of the Hydraulics Division, ASCE* 99:1083.

Among recent graduate theses are:

Bedford, K. 1974. Numerical Investigation of Stably Stratified, Wind-Driven Cavity Flow. Ph.D. thesis. (Professor Liggett.)

Newbold, J. D. 1973. Oxygen Depletion in a Thermally Stratified Lake. M.S. thesis. (Professor Liggett.)

Verma, R. D. 1969. Physical Analysis of the Outflow from an Unconfined Aquifer. Ph.D. thesis. (Professor Brutsaert.)

Weisman, R. N. 1973. A Problem in Turbulent Diffusion: Evaporation and Cooling of a Lake Under Unstable Atmospheric Conditions. Ph.D. thesis. (Professor Brutsaert.)

Sanitary Engineering

Graduate study in this major subject is concerned with the principles, phenomena, and engineering techniques that are applicable to the maintenance of natural environmental quality at levels beneficial to man. Instruction and research focus on pertinent biological, chemical, physical, and engineering knowledge, and on the use of this knowledge, along

with analytical, computational, and laboratory skills, in the planning, analysis, and design of facilities, systems, and policies that are essential to the achievement of environmental quality objectives.

More than fifteen advanced courses are offered by faculty members of the Department of Environmental Engineering who are specialists in this subject area. First-year graduate students take core courses in the major subject and electives in a minor subject of their choice. These electives are selected from a wide range of supporting courses in the biological and physical sciences, applied mathematics, planning, and engineering; included are such subjects as environmental quality, hydraulics and hydrology, environmental systems engineering, and water resources planning and management.

Graduate students and faculty members in this subject area carry out research in the phenomena and the technology fundamental to water quality control; waste processing, disposal, and management; and water resource planning and management.

The following papers are representative of recent research supervised by sanitary engineering professors:

Behn, V. C. 1973. *Discharges of industrial waste to municipal sewer systems.* Technical report no. 60, Water Resources and Marine Sciences Center, Cornell University.

Bisogni, J. J., and Lawrence, A. W. 1973. Kinetics of Microbially Mediated Methylation of Mercury in Aerobic and Anaerobic Aquatic Environments. Paper read at 46th Annual Conference of the Water Pollution Control Federation, October 1973, in Cleveland, Ohio.

Gates, C. D. 1973. Recover, reuse, recycle: New approaches to the solid waste problem. *Engineering: Cornell Quarterly* 7(4):18.

Lawrence, A. W., and Middleton, A. C. 1973. Cost Optimization of Activated Sludge Wastewater Treatment Systems. Paper read at 166th National Meeting of the American Chemical Society, 30 August 1973, in Chicago, Illinois.

Wall, J. F., and Dworsky, L. B. 1972. Federal reorganization to protect the environment. *Engineering Issues (Proceedings of the American Society of Civil Engineers)* 98(PP2):227.

Examples of recent graduate thesis work are:

Frenette, R. E. 1972. A Water Quality Management Strategy for the Great Lakes. M.S. thesis. (Professor Dworsky.)

Kellogg, S. R. 1974. Removal of Color from Red Beet and Cherry Processing Wastes Employing Granular Activated Carbon. M.S. thesis. (Professor Loehr.)

Remote sensing techniques are used to locate preglacial buried channels in a graduate research project in the Program in Measurement and Remote Sensing.

Milnes, T. R. 1972. Dynamic Modeling of the Completely Mixed Activated Sludge Process: Laboratory and Mathematical Studies. Ph.D. thesis. (Professor Lawrence.)

Molinari, P. J. 1973. A Simulation of Nitrification in an Aquatic Environment Through the Use of a Continuous Flow, No Solids Recycle System. M.S. thesis. (Professor Gates.)

Palumbo, J. J. 1973. An Investigation of the Methylation and Distribution of Mercury in a Biological Wastewater Treatment System. M.S. thesis. (Professor Bisogni.)

Powell, L. A. 1973. Phosphorus Removal in Subsurface Sand Filters. M.S. thesis. (Professor Behn.)

Structural Engineering

One of the major branches of Cornell's program in civil and environmental engineering is structural engineering. Research projects involving graduate students are grouped in several areas.

Light Gage Steel Structures. A long-term program of research at Cornell, sponsored largely by the American Iron and Steel Institute, has provided the basis for United States design specifications for this broad class of structures. Current research topics include diaphragm effects of steel panels, stability of compression and flexural members, design criteria for compact sections, and connection behavior.

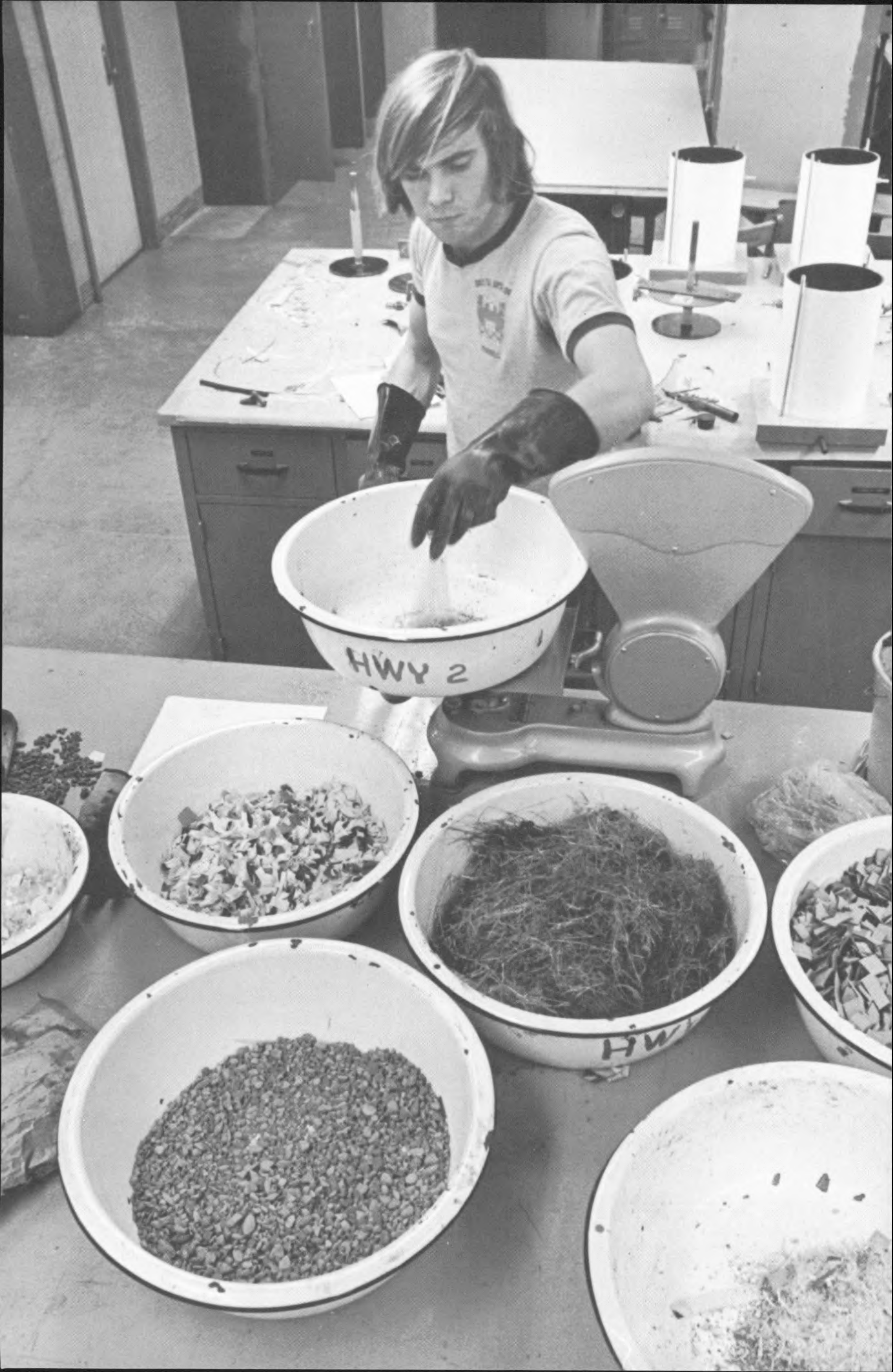
Reinforced Concrete. Cornell has long been regarded as one of the important centers for research on reinforced concrete structures; building code provisions relating to deflections, cracking, and bond have followed directly from research here. Current programs include sponsored research on shear walls, deep beams, and shear transfer across cracks in nuclear containment structures.

Modeling Behavior of Reinforced Concrete. Pioneering work has been accomplished during the past decade in the development of techniques for small-scale modeling of the behavior of reinforced and prestressed concrete structures, such as shells, frames under reversing loads, and prestressed concrete pressure vessels.

Concrete Materials. Fundamental research on microcracking in concrete has provided a rational explanation for the unique shape of the stress-strain curve. Recently attention has been directed to the stress-strain relations and strength of plain concrete under biaxial stresses.

Finite Element Analysis. Recent major sponsored research projects have dealt with the finite element analysis of shells, including dynamic response and stability. Finite element analysis is also an integral part of many of the other areas of research discussed here, and has been applied to the pollution analysis of lakes.

Probability and Structural Safety. Since a rational approach to structural safety must be based on probabilistic concepts, Cornell faculty members and graduate students have been active in developing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ways of implementing this approach. The research and professional committee activities of Cornell specialistis have been of fundamental importance in the development of structural safety codes.

Some of the research efforts in the various aspects of structural engineering are indicated by the following representative faculty publications:

Atan, Y., and Slate, F. O. 1973. Structural lightweight concrete under biaxial compression. *Journal of the American Concrete Institute* 70:182.

Dhalla, A. K., and Winter, G. 1974. Steel ductility requirements. Steel ductility measurements. *Proceedings of the ASCE, Journal of the Structural Division* 100(ST2): in press.

Gergely, P. 1973. Cracking and crack control. In *Proceedings of the ASCE-IABSE international conference on tall buildings*, p. 24.9.

Liu, T. C. Y.; Nilson, A. H.; and Slate, F. E. 1972. Biaxial stress-strain relations for concrete. *Proceedings of the ASCE, Journal of the Structural Division* 98:1025.

McGuire, W. 1974. Prevention of progressive collapse. To be published in *Proceedings of the ASCE-IABSE regional conference on tall buildings* (Bangkok).

Simaan, A., and Peköz, T. 1973. Wall stud design criteria. In *Proceedings of 2nd specialty conference on cold formed steel structures,* p. 467. Rolla: University of Missouri.

Thomas, G. R., and Gallagher, R. H. 1973. *Triangular finite element for shells: linear analysis.* National Aeronautics and Space Administration report.

White, R. N., and Chowdhury, A. H. 1973. Behavior of Multi-Story Reinforced Concrete Frames Subjected to Severe Reversing Load. Preliminary report, IABSE Symposium, September 1973, in Lisbon.

Winter, G., and Nilson, A. H. 1973. *Design of concrete structures*, 8th edition. New York: McGraw-Hill.

Recent graduate theses in structural engineering include:

Ammar, A. R. 1973. Analysis of Light Gage Steel Shear Diaphragms. Ph.D. thesis. (Professor Nilson.)

Banerjee, A. K. 1973. Analysis of Orthotropic Hyperbolic Paraboloid Shells. Ph.D. thesis. (Professor Gergely.)

Celebi, N. 1971. Diaphragm Braced Channel and Z Section Beams. Ph.D. thesis. (Professor Winter.)

Chang, T. C. 1973. Inelastic Behavior of Concrete Infilled Frames. Ph.D. thesis. (Professor White.)

Chowdhury, A. H. 1973. An Experimental and Theoretical Investigation of the Inelastic Behavior of Reinforced Concrete Multisensory Frame Models Subjected to Simulated Seismic Loads. Ph.D. thesis. (Professor White.)

DeWolf, J. 1973. Local and Overall Buckling of Cold-Formed Compression Members. Ph.D. thesis. (Professor Winter and Peköz.)

Falby, W. E. 1973. Minimum Weight Design of Compression Panels. 1973. Ph.D. thesis. (Professor Gallagher.)

Laible, P. J. 1973. Interface Shear Transfer and Applications in the Dynamic Analysis of Nuclear Containment Vessels. Ph.D. thesis. (Professor Gergely.)

Lien, S. 1971. Finite Element Thin Shell Pre- and Post-Buckling Behavior. Ph.D. thesis. (Professor Gallagher.)

Miller, C. 1972. Analysis of Multistory Frames with Light Gage Steel Panel Infills. Ph.D. thesis. (Professors Nilson and Sexsmith.)

Simaan, A. 1973. Buckling of Diaphragm-Braced Columns of Unsymmetrical Sections and Application to Wall Stud Design. Ph.D. thesis. (Professors Winter and Peköz.)

A model mix of municipal solid refuse is prepared for experimental work in landfill engineering.

Structural Mechanics

This subject area can be studied as a minor in the M.S. or Ph.D. degree programs. Courses emphasize the analytical aspects of structural engineering, such as advanced analysis techniques, dynamics of structures, and shell theory. A minor in structural mechanics is especially suitable for M.S. candidates who have an interest in analysis but who do not have time to satisfy the requirements for a major in structural engineering and a full minor in theoretical and applied mechanics.

Transportation Engineering and Planning

The major emphasis in this area of teaching and research is in the application of analytical techniques to the handling of transportation problems. The approach is typically multimodal and emphasis is given to problems of urban transportation. Specific interests of faculty members lie in the areas of demand modeling for passenger and freight movements, the development of mass transit systems, airport planning and operation, traffic flow theory, transportation systems analysis, and highway design.

An example of publications based on research in his area is:

Meyburg, A. H. 1972. An analysis of the relationships between intercity passenger transportation and the socioeconomic characteristics of metropolitan areas. *Transportation Research Forum—Proceedings* XIII (1):271.

Recent theses in this subject area include:

Corredor, A. 1973. Maximizing Accessibility: A Criterion for Long-Range Planning of Highway Investments in Developing Countries. Ph.D. thesis. (Professor Meyburg.)

Groninger, K. 1971. An Algorithm for Synthesizing Optimal Transportation Networks. Ph.D. thesis. (Professor Fisher.)

Orloff, C. 1973. Routing and Scheduling a Fleet of Vehicles: The School Bus Problem. Ph.D. thesis. (Professor Lynn.)

Parker, N. 1971. A Systems Analysis of Route Location. Ph.D. thesis. (Professor Fisher.)

Toomey, J. 1973. The Effects of Entrance Ramp Control on Peak-Period Freeway Operations. M.S. thesis. (Professor Meyburg.)

Water Resource Systems

For graduate students interested in water resources planning and management, there are numerous interdisciplinary degree programs available through the Field of Civil and Environmental Engineering. Ph.D. degree candidates who wish to obtain some quantitative skills in the development of mathematical management and planning models and their application to the solution of water resource problems can arrange a major in water resources systems and minors in economic theory, operations research, environmental quality, public policy, or other appropriate subjects. Both Ph.D. and M.S. degree candidates who wish to become acquainted with some of the management and planning issues of water resources development and some of the relevant legislation can select a minor in the area of water resources, described in the following section.

Throughout the University, there are more than one hundred courses offered and about an equal number of staff members involved in some aspect of water resources or aquatic sciences. Cornell's Water Resources and Marine Sciences Center offers considerable assistance in both course work and research.

The variety of research projects in this area is suggested by the following faculty publications and theses of students with major or minor programs in water resources:

Loucks, D. P. (with Jacoby, H. D.) 1972. The combined use of optimization and simulation models in river basin planning. *Water Resources Research* 8(6):1401.

Burkholder, J. 1973. Natural Resources Management in the Great Lakes Basin. M.S. thesis. (Professor Dworsky.)

El-Sahragty, M. 1974. Methods for Analyzing Storm Water Storage and Treatment Systems. Ph.D. thesis. (Professor Loucks.)

Foster, J. 1973. Cost Sharing in Water Pollution Abatement Facilities—Some Economic and Political Consequences. M.S. thesis. (Professor Dworsky.)

Gablinger, M. 1971. Reservoir Regulation—Some Techniques and Results. Ph.D. thesis. (Professor Loucks.)

Lewinger, K. 1973. A Method of Data Reduction for Water Resources Information Storage and Retrieval. M.S. thesis. (Professor Loucks.)

Turgeon, A. 1974. Optimal Operation of Hydro-Steam Power Systems. Ph.D. thesis. (Professor Shoemaker.)

Water Resources

Students who plan to major in an area of civil and environmental engineering may be interested in a minor in Water Resources. Such a program enables advanced-degree candidates to gain breadth of knowledge in water resource planning and management. Thesis research is carried out in the major subject area.

Faculty Members and Their Research and Teaching Interests

Vaughn C. Behn, P.E., Dr.Eng. (Johns Hopkins): *sanitary engineering; industrial wastewater control*

Donald J. Belcher, C.E., P.E., M.E., M.S. (Purdue): *aerial photography*

Philip L. Bereano, J.D., M.R.P. (Cornell): *environmental law and public policy; technology assessment*

James J. Bisogni, Jr., Ph.D. (Cornell): *sanitary engineering; applied aquatic chemistry*

Wilfried H. Brutsaert, Ph.D. (California at Davis): *hydraulics, hydology, and ground water flow*

Leonard B. Dworsky, M.S. (American University): *water resources planning and management*

Gordon P. Fisher, P.E., D.Eng. (Johns Hopkins): *environmental systems; traffic flow theory and traffic engineering*

Richard H. Gallagher, P.E., Ph.D. (SUNY-Buffalo): *digital computer applications in structural analysis and optimization; plate and shell buckling*

Charles D. Gates, M.S. (Harvard): *sanitary engineering; water quality control*

Peter Gergely, P.E., Ph.D. (Illinois): *structural mechanics; shells; dynamics; reinforced concrete*

J. Neil Kay, Ph.D. (Northwestern): *soil mechanics; foundation engineering*

Alonzo Wm. Lawrence, P.E., Ph.D. (Stanford): *sanitary engineering; environmental quality engineering*

Ta Liang, Ph.D. (Cornell): *aerial photography, physical environment; remote sensing*

James A. Liggett, Ph.D. (Stanford): *hydraulics, fluid mechanics, and hydrology*

Raymond C. Loehr, Ph.D. (Wisconsin): *agricultural wastes*

Daniel P. Loucks, Ph.D. (Cornell): *water resource and environmental quality management systems; multiobjective evaluation methods; engineering-economic-ecologic systems analysis*

Walter R. Lynn, Ph.D. (Northwestern): *environmental systems analysis; public health; water quality management models*

George B. Lyon, P.E., M.S. (University of Iowa): *surveying*

William McGuire, P.E., M.C.E. (Cornell): *performance and design of metal structures*

Arthur J. McNair, C.E., P.E., M.S. (Colorado): *geodesy-photogrammetry*

Arnim H. Meyburg, Ph.D. (Northwestern): *urban transportation and planning; transportation systems analysis*

Arthur H. Nilson, P.E., Ph.D. (California at Berkeley): *behavior and design of reinforced concrete; prestressed concrete; light-gage steel structures*

Teoman Peköz, Ph.D. (Cornell): *stability of cold-formed, thin-walled steel structures; experimental methods*

Dwight A. Sangrey, Ph.D. (Cornell): *soil mechanics and foundation engineering*

Richard E. Schuler, Ph.D. (Brown): *public finance problems; econometric analysis*

Robert G. Sexsmith, Ph.D. (Stanford): *probabilistic approaches in structural engineering*

Christine Shoemaker, Ph.D. (USC): *water resource systems; mathematical ecology*

Floyd O. Slate, Ph.D. (Purdue): *physical and chemical properties of engineering materials*

Shaler Stidham, Jr., Ph.D. (Stanford): *queuing systems; transportation systems; traffic flow theory*

Howard M. Taylor, 3d, Ph.D. (Stanford): *applied probability and statistics with emphasis on public systems problems*

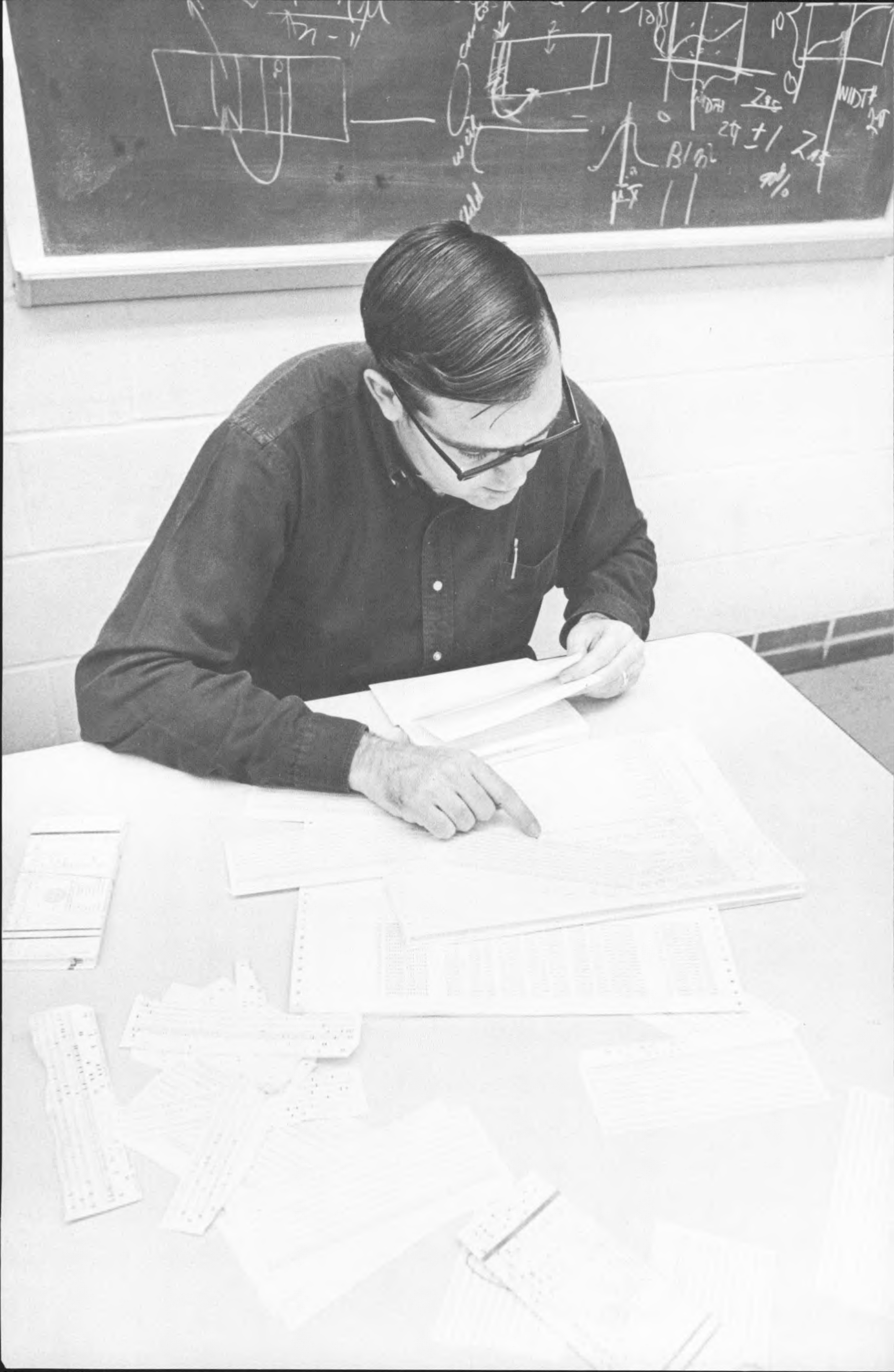
Gareth R. Thomas, Ph.D. (Cornell): *structural engineering*

Richard N. White, P.E., Ph.D. (Wisconsin): *model analysis; nuclear reactor structures; concrete structures*

George Winter, Ph.D. (Cornell): *performance, strength, and stability of steel and concrete structures*

Further Information

Further information may be obtained by writing to: Graduate Field Representative, Civil and Environmental Engineering, Hollister Hall, Cornell University, Ithaca, New York 14850.



Computer Science

Computer science, the science of information, includes study of the nature and properties of information, its structures and classification, its storage and retrieval, and the various types of processing to which it can be subjected. The physical machines that perform these operations, the elemental units of which the machines are composed, and the organization of these units into efficient information-processing systems are also of concern.

Various aspects of computer science are closely related to many other fields. The fundamental theory of information processing and the exploration of the limits of the abilities of computing machines are topics in pure and applied mathematics. Numerical analysis, which has to do with the development as well as the accuracy and efficiency of practical numerical procedures, is in the area of applied mathematics. Students of computer science and electrical engineering share an interest in the characteristics of physical machines and in computer design. Language structure and translation are of concern in both computer science and linguistics. The implications of current data-processing technology for the organization and control of industrial and business operations are also pertinent to industrial engineering and business administration. Investigations in the area of artificial intelligence are of interest in the study of psychology and biology. In the past, these subjects usually have been pursued as parts of various fields. Today, increasing recognition is being given to the strong common basis of all of this work, and computer or information science is an independent discipline at many leading institutions.

Cornell's leadership in the development of computer science is indicated by the following texts written at Cornell and widely used in the field:

Conway, R. W., Maxwell, W. L., and Miller, L. W. 1967. *Theory of scheduling.* New York: Addison-Wesley.

Conway, R. W., and Gries, D. 1973. *An introduction to programming: a structured approach using PL/I and PL/C.* Cambridge, Massachusetts: Winthrop.

The processing of information and its storage and retrieval are among subjects of research in computer science.

Gries, D. 1971. *Compiler construction for digital computers.* New York: Wiley.

Hartmanis, J., and Stearns, R. E. 1966. *Algebraic structure theory of sequential machines.* Englewood Cliffs, New Jersey: Prentice-Hall.

Hopcroft, J. E., and Ullman, J. D. 1969. *Formal languages and their relation to automata.* New York: Addison-Wesley.

Salton, G. 1969. *Automatic information organization and retrieval.* New York: McGraw-Hill.

Salton, G., et al. 1971. *The SMART retrieval system: experiments in automatic document processing.* Englewood Cliffs, New Jersey: Prentice-Hall.

There are about fifty-five graduate students in computer science at the present time. Out of approximately two hundred applicants, the Field admits twenty to twenty-five new students each year. Persons who cannot enroll as full-time students are discouraged from applying. (Students having assistantships or fellowships are normally regarded as full-time students.)

As prerequisites for candidacy for an advanced degree in computer science, a student is expected to have had significant experience in programming a digital computer and, depending upon the particular area of specialization chosen, an appropriate background in mathematics, engineering, or related areas which would 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.

Students interested primarily in computer components and logical design rather than in the use of computers may find it more appropriate to consider the Field of Electrical Engineering.

Facilities

The central computing facility at Cornell is a 2.8-megabyte IBM 360/65, linked to high-speed terminals at various locations on campus. The College of Engineering is served through two such terminals, as well as by a number of teletypewriter terminals. The central processor is slated for replacement in 1974 by a 3-megabyte 370/168 system.

Numerous other machines, ranging up to a PDP-10, are also available, but almost all computer science use has involved the central facility.

Areas of Research

The research program is designed to provide an atmosphere in which both students and faculty can make major contributions and influence the development of computer science.

Major research efforts are directed toward analysis of algorithms, the theory of computation, compiler construction, operating systems, programming languages, information storage and retrieval, symbol maniplulation, and numerical analysis.

Instruction and research in related topics are carried out in other graduate fields. These include simulation, data processing, linguistics, control theory, mathematical programming, network and graph theory, and electrical engineering. In particular, the Field of Computer Science maintains a close relationship with the Field of Operations Research at Cornell.

Brief descriptions of the major research activities in the Field of Computer Science at Cornell are given below. The examples range from abstract mathematics to practical implementations and experiments in programming systems.

Theory of Algorithms

There is a growing belief that a relatively small number—perhaps a score—of fundamental processes dominate all of computing, both applications and systems programs. The study of algorithms is the attempt to identify these fundamental processes and to find efficient and possibly optimal algorithms for their execution. Recent results have concerned high-precision multiplication, matrix multiplication, evaluation of polynomials, pattern matching, sorting, and manipulation of graphs. In many cases, marked improvements in performance have been obtained. For example, while it has long been "known" that matrix multiplication varies with the cube of the order n, it has recently been shown that at most $n^{2.81}$ operations are required.

In general, work by Professors Hopcroft, Kou, and Tarjan is being concentrated on the fundamental features of the basic algorithms. Concise models of the pertinent features are being formulated and theoretical results concerning asymptotic running times and lower bounds are being obtained.

Examples of recent Ph.D. theses in this area are:

Musinski, J. A. 1973. Determining the Complexity of Matrix Multiplication and Other Bilinear Forms. (Professor Hopcroft.)

Reingold, E. M. 1971. On Some Optimal Algorithms. (Professor Hartmanis.)

Theory of Computation

Primary activities in this area are concerned with the theory of automata, formal languages, computational complexity, applications of recursive function theory and logic in computer science, and program schemata.

As a result of current work by one group in the Field, there is emerging a theory of feasible computation which has strong connections to recursive function theory through a concern for general principles and to the theory of algorithms through a concern for the feasibility of natural problems. These connections are being investigated by several professors and their students. There were three doctoral theses in this area in 1973–74:

Mehlhorn, K. Computational Complexity. (Professor Constable.)

Baker, T. Computational Complexity and Nondeterminism in Flowchart Programs. (Professor Hartmanis).

Hunt, H. B. On the Time and Tape Complexity of Languages. (Professor Hopcroft.)

The study of program schemata has led to work that relates the theory of computing to a study of the semantics of programming languages. There were two theses in this area in 1972–73:

Brown, J. S. Program Schemata and Information Flow: A Study of Some Aspects of the Schema Power of Data Structures. (Professor Gries.)

Cherniavsky, J. C. Logical Theories for Representing Flowchart Schemata. (Professor Constable.)

Other recent work in this area concerns questions about the computational complexity of schemata and the analysis of algorithms for manipulating them. Publications based on this research include the texts, cited above, by Hartmanis and Stearns and by Hopcroft and Ullman, and also journal articles such as the following:

Constable, R. L., and Gries, D. 1972. On classes of program schemata. *SIAM Journal of Computing* 1(1):66.

Hartmanis, J., and Hopcroft, J. 1971. Overview of the theory of computational complexity. *Journal of the ACM* 18:444.

Compiler Construction

The PL/C compiler, a very efficient compiler for a subset of PL/I, was implemented under the leadership of Professor Conway. The compiler is unusual in that it attempts to make plausible repairs of all errors so that every program reaches execution. It has become the standard instructional system for PL/I—it is used at more than one hundred universities throughout the world. A description is available in published form:

Conway, R. W., and Wilcox, T. R. 1973. Design and implementation of a diagnostic compiler for PL/I. *Communications of the ACM* 16(3):169.

Further work on PL/C is directed toward expanding the subset of PL/I and improving both efficiency and error repair. A group headed by Professor Moore is developing an interactive version of the system.

The department is also involved in the study of automatic translator writing systems and their practical application. Professor Gries' book on compiler construction, cited above, reflects this work.

Information Organization and Retrieval

Research directed by Professors Salton and Kou deals with the analysis of information retrieval algorithms and the design of fully automatic retrieval systems. The work includes the design and evaluation of file organization systems, automatic classification and search methods, language analysis procedures, and interactive retrieval processes.

A research project headed by Professor Salton has led to the publication in the past few years of two textbooks (cited above). The participation of graduate students in this program is indicated by thesis work completed recently:

Yu, C. 1973. Theory of Indexing and Classification. Ph.D. thesis.

Weiss, S. 1970. A Template Approach to Natural Language Analysis for Information Retrieval. Ph.D. thesis.

In another project in this area, Professors Conway and Maxwell have designed and implemented a database maintenance and information retrieval system. This system, which features unusual facilities for file security, is described in a recent journal publication:

Conway, R. W.; Maxwell, W. L.; and Morgan, H. L. 1972. On the implementation of security measures in an information system. *Communications of the ACM* 15(4):211.

With Professor Moore, this work on security measures is continuing.

Numerical Analysis

Professors Bunch, Dennis, and Moré are carrying on research in the areas of numerical linear algebra, solutions of nonlinear systems of equations, and nonlinear optimization. Mathematics professors Bramble, Payne, and Schatz are primarily interested in the numerical solution of partial differential equations. Ph.D. theses have been written on approximation theory, solutions of nonlinear systems of equations, and solutions of matrix polynomial and λ-matrix problems. A representative doctoral thesis is:

Boggs, P. T. 1970. The Solution of Nonlinear Operator Equations by A-Stable Integration Techniques. (Professor Dennis.)

Faculty Members and Their Research Interests

The faculty of the graduate Field of Computer Science consists of the staff of the Department of Computer Science and members of other departments who teach graduate courses and supervise students in areas of study related to computer science. The other departments represented in the Field are Mathematics, City and Regional Planning, Plant Breeding and Biometry, Theoretical and Applied Mechanics, and Operations Research.

Henry Block, Ph.D. (Iowa State): *theory of automata, pattern recognition*

James Bramble, Ph.D.(Maryland): *numerical analysis*

James R. Bunch, Ph.D. (California at Berkeley): *numerical analysis*

Robert Constable, Ph.D. (Wisconsin): *computational complexity*

Richard Conway, Ph.D. (Cornell): *digital simulation, management, information systems, operating systems*

John E. Dennis, Ph.D. (Utah): *numerical analysis*

David Gries, Dr. rer. nat. (Technische Höchschule, München): *programming languages, compiler construction*

Juris Hartmanis, Ph.D. (California Institute of Technology): *theory of computation*

John Hopcroft, Ph.D. (Stanford): *theory of computation, analysis of algorithms*

Lawrence T. Kou, Ph.D. (California at Berkeley): *analysis of algorithms*

William Maxwell, Ph.D. (Cornell): *digital simulation, operations research*

Charles G. Moore, Ph.D. (Michigan): *operating systems, system architecture*

Jorge J. Moré, Ph.D. (Maryland): *numerical analysis*

Anil Nerode, Ph.D. (Chicago): *logic, applied mathematics*

Christopher Pottle, Ph.D. (Illinois): *signal processing, systems theory*

Gerard Salton, Ph.D. (Harvard): *information organization and retrieval*

Robert Tarjan, Ph.D. (Stanford): *analysis of algorithms*

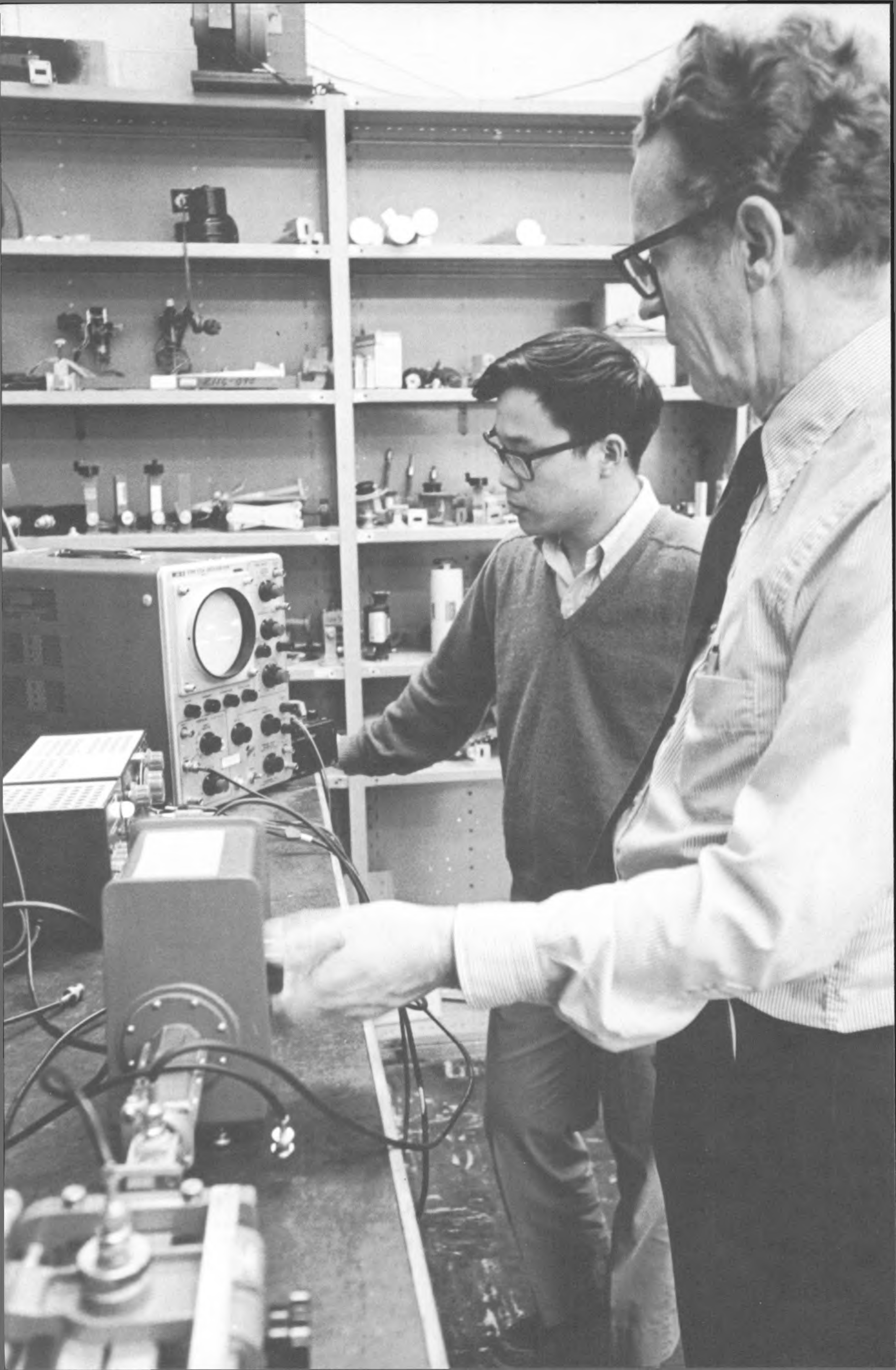
Ray Teitelbaum, Ph.D. (Carnegie-Mellon): *programming languages and systems*

Robert Walker, Ph.D. (Princeton): *numerical analysis, combinatorics*

John Williams, Ph.D. (Wisconsin): *formal languages, programming languages, compiler construction*

Further Information

Additional information may be obtained by writing to the Graduate Field Representative, Computer Science, Upson Hall, Cornell University, Ithaca, New York 14850.



Electrical Engineering

The largest group of graduate students in any of the engineering and applied science fields at Cornell is enrolled in the Field of Electrical Engineering. These students conduct research on topics that range from planetary studies to electronic circuit design. A few examples of current research activities are projects in the areas of algebraic coding, bioelectronics, computer-aided circuit design, data compression studies, the application of control theory to power system stability, multiterminal communications systems, pattern recognition and speech processing, the ionosphere and magnetosphere of Earth and Jupiter, high-energy plasmas and thermonuclear fusion, integrated circuit technology, molecular and chemical lasers, microwave solid state devices, thin film optical devices, electric vehicles, and an unmanned Martian roving vehicle.

The broad spectrum of research activities in electrical engineering can be roughly divided into two general areas, electrophysics and systems. Research in electrophysics encompasses the study of the physical properties of matter and the environment, and of devices that utilize these properties. Systems research is concerned with complexes formed by the interconnection of devices and with the response of these systems to various excitations. Of course, there are many points of mutual interaction between these two disciplines. At Cornell, the research projects range over a wide spectrum within these two disciplines and within the areas of overlap.

There are currently about seventy-five students enrolled in the Master of Science and Doctor of Philosophy degree programs; about half have major interests in electrophysics and about half in systems. This number is large enough to achieve the critical mass that is conducive to effective research in most areas, and yet is small enough to enable the students and faculty to get to know one another. Graduate students often learn as much from each other as they do from their formal studies; therefore, it is important to have students working in related research areas and to provide an environment in which interaction is encouraged. About sixty additional students are enrolled in the one-year Master of Engineering (Electrical) program.

Laboratory course work is part of the graduate program in electrical engineering.

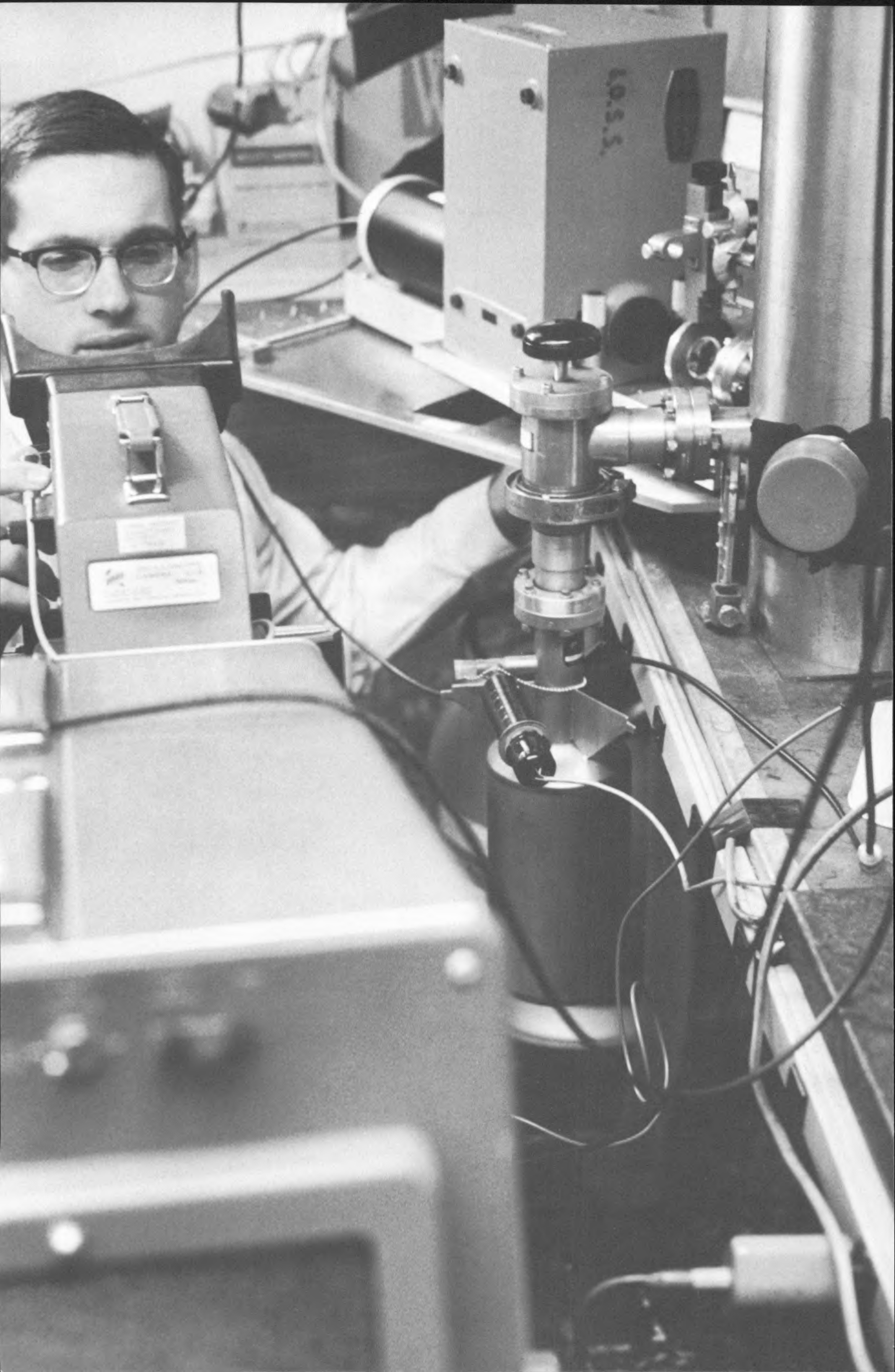
Since there are no formal course requirements for the M.S. and Ph.D. programs, graduate students have a major responsibility in curricular planning. Each student, in consultation with the faculty members of his Special Committee, devises a course of study tailored to his own particular interests and background. The Field of Electrical Engineering offers more than sixty graduate-level courses, and many other advanced courses of interest to graduate students in electrical engineering are offered throughout the University. Of particular importance are those in the Fields of Applied Physics, Astronomy and Space Sciences, Computer Science, Mathematics, and Physics.

Facilities

Many of the research projects in the Field of Electrical Engineering are carried out in the laboratories of Phillips Hall, the center for activity in electrical engineering in the College of Engineering. Several other University laboratories and research centers also accommodate electrical engineering research groups.

In the area of electrophysics, the facilities at Cornell include special laboratories for ionospheric physics and radio-wave propagation, microelectronics and intregrated circuits, microwave solid state devices, optics and spectroscopy of solids and thin films, and quantum electronics. Some research groups use the facilities of Cornell's Materials Science Center or its Laboratory of Plasma Studies. Much of the research in ionospheric physics and radar astronomy is carried out at the National Astronomy and Ionosphere Center operated by Cornell in Puerto Rico.

In the area of systems, the facilities at Cornell include special laboratories for research in active networks and digital filters, bioelectronics, control systems, and digital systems. Some groups also use the facilities of the Laboratory of Neurobiology and Behavior.



Highly important for electrical engineering research, particularly in the area of systems, are the various computer facilities available at Cornell. The University's extensive central computer services are used in many of the research projects in both electrophysics and systems. In addition, the School of Electrical Engineering has a PDP 11/40 minicomputer system with extensive peripheral devices which is available to all faculty members and students for research and instructional use. This computer is interfaced with an analog computer to provide a hybrid facility.

Areas of Research

Descriptions of some of the current research projects are given below, along with listings of a few of the recent theses and publications produced by Field faculty members and graduate students. A complete list of faculty publications is available from the School of Electrical Engineering, Phillips Hall.

Bioelectronics

Research in this field involves the application of electrical engineering techniques to biological systems and includes studies of animal sound communication, sensory processing in the nervous system, electrophysiological techniques and instrumentation, and dynamics of cellular proliferation of cancer. Current efforts include studies of vocal communication in frogs and toads, the encoding of complex sounds in the auditory nervous system, mechanisms and models underlying periodic electrical activity of single pacemaker nerve cells and circadian oscillation in the sea snail eye, and models for chemical control of cancer.

Professors Capranica and Kim direct these research efforts in bioelectronics. Among their publications are the following:

Kim, M. 1973. The effects of metabolic inhibitors on and a nonlinear oscillator model of pacemaker neurons. In *Regulation and control in physiological systems,* ed. A. S. Iberal and A. C. Guyton, p. 553. Pittsburgh: Instrument Society of America.

Capranica, R. R. 1972. Sensory physiology of amphibians. Chapter in *Physiology of amphibia,* vol. 2, ed. B. Lofts. New York: Academic Press.

Graduate thesis topics in progress include: Response Properties of Single Nerve Cells Involved in Sound Localization; Frequency Response of Acoustic Receptor Organs; Neural Detection of Frequency-Modulated Sounds; A Neurological Control Model of the Peripheral Visual System of Aplysia; Pharmacological and Systems Study of Pacemaker Neurons; and Optical Control of Tumor Growth.

Measurement of the electroluminescent properties of thin-film metal-insulator-semiconductor structures was part of a graduate research project in electrical engineering.

Computer Structures and Design

Since current integrated circuit technology suggests that computing devices might be implemented by using cellular arrays, the structure and design of such arrays are being studied in a current project.

In the area of quantitative computer architecture, algorithmic and quantitative approaches to the design, implementation, and evaluation of computers are being investigated.

Professors Torng and Vrana and their students are working on these projects. A recent thesis and resulting publication is representative of graduate research in this area:

Cornell, R. G. 1973. The Synthesis and Evaluation of Cellular Computers. Ph.D. thesis. (Professor Torng.) A publication based on this research is: Torng, H. C., and Cornell, R. G. 1971. Cellular arrays and arithmetic units: A synthesis procedure. In *Proceedings of the PIB symposium on computers and automata,* p. 527.

Control Theory

Theoretical problems associated with the control of linear and nonlinear systems, including problems of stochastic control, are being studied. The techniques developed in these investigations are being applied to control problems in the areas of power systems (improving transient stability), ecological systems (insect pest control), tracking systems, and guidance systems for reentry vehicles.

In the area of multivariable linear systems, the design of insensitive control systems is being investigated. By identifying certain invariant properties of a system and relating them to the design objectives it is possible to produce an insensitive solution.

An important part of the research in control theory is focused on successive approximation techniques. Computer techniques (analog, digital, and hybrid) are emphasized, particularly for optimization in real time. The application of the theory of functional analysis to control problems provides a background for new computational procedures. Recently, real time controllers, designed on the basis of the research in optimization theory, have been built and tested at an industrial laboratory.

The design of terminal guidance systems for reentry vehicles is studied by using either the classical approach based on proportional navigation or modern control theory.

Professors Kim, Thomas, and Thorp direct research projects in this area.

Recent theses and publications include:

Barnard, R. D.; Thomas, R. J.; and Meisel, J. 1971. On Klopfenstein's method and solutions of nonlinear equations. In *Proceedings of 4th Hawaii conference on system sciences,* p. 546. Honolulu: University of Hawaii.

Kim, M., and Grider, K. V. 1973. Terminal guidance for impact attitude angle constrained flight trajectories. *IEEE Transactions on Aerospace and Electronic Systems* AES-9(6):852.

Lee, S.-Y. 1973. The Duality Principle and its Application to Optimal Control of Linear Systems. Ph.D. thesis. (Professor Thorp.)

Thorp, J. S. 1973. The singular pencil of a linear dynamical system. *International Journal of Control* 18:577.

Electromagnetic Theory and Microwave Devices

Research is being conducted on the application of symmetry analysis to electromagnetic theory, with particular emphasis on microwave and optical circuits and devices. The electromagnetic properties of dispersive media are also being investigated.

This research is directed by Professor McIsaac. An example of graduate thesis work is:

Knorr, J. B. 1970. Electromagnetic Applications of Group Theory. Ph.D. thesis. (Professor McIsaac.) This work resulted in the publication: Knorr, J. B., and McIsaac, P. R. 1971. A group theoretic investigation of the single wire helix. *IEEE Transactions on Microwave Theory and Techniques* MTT-19:854.

High Energy Plasmas

Plasma research conducted by the faculty and students of the School of Electrical Engineering is coordinated by the interdepartmental Laboratory of Plasma Studies, which affords a broad base from which to operate. Both theoretical and experimental programs are pursued. The extensive laboratory facilities include both large-scale plasma devices and small-scale apparatus.

Programs in which members of the School are participating include projects and studies in intense relativistic electron beams and their interaction with plasmas; lasers and their interaction with plasmas; collisionless plasma turbulence (waves and transport); nonlinear waves and plasma instabilities; and numerous problems involved in controlled thermonuclear power research.

Research on megavolt, terawatt electron beams, and on turbulent heating are especially noteworthy, since pioneering work in these areas has been carried out at Cornell. The relativistic electron beam research is directed largely to the study of heating and confinement of thermonuclear plasmas. Other work using these beams is directed to microwave generation and beam dynamics. In the turbulent heating experiment, the possibilities for heating a fusion plasma by strong turbulence are being investigated. Theoretical investigations include studies of collective processes by which relativistic beams transfer their energy to plasmas; stability and equilibrium of electron beams in different geometrical configurations; and plasma turbulence. Some of these problems are simulated by numerical models solved on the largest available modern digital computers.

Electrical engineering faculty members who are directing plasma research include Professors Liboff, Linke, McFarlane, Nation, Ott, Sudan, Wharton, and Wolga. Other units at Cornell that participate in the Laboratory of Plasma Studies activities include Mechanical and Aerospace Engineering, Applied Physics, Chemistry, Nuclear Science and Engineering, and Physics.

Recent theses and papers by professors and graduate students are:

Gardner, W. L. 1973. A Study of Combination, Neutralization, and Pinch Mode Propagation of an Intense, Relativistic Electron Beam. Ph.D. thesis. (Professor Nation.) A paper based on this research is: Davitian, W. H.; Gardner, W. L.; and Nation, J. A. 1972. Intense Relativistic Electron Beams for Nuclear Fusion. Presented at 5th European Conference on Nuclear Fusion, Grenoble, France.

Lee, R. E. 1971. Return Current Induced by a Relativistic Electron Beam Propagating in a Magnetized Plasma. Ph.D. thesis. (Professor Sudan.) A paper by the same title, with R. Lee and R. N. Sudan as authors, was published in 1971 in *Physics of Fluids* 14:1213.

Liboff, R. L. 1972. Relativistic excitation of cavity modes. *Journal of Mathematical Physics* 13:1828.

Ott, E.; Manheimer, W. M.; Book, D. L.; and Boris, J. P. 1973. Model equations for mode coupling saturation in unstable plasmas. *Physics of Fluids* 16:855.

Sandel, F. L. 1973. The Interaction of a Relativistic Electron Beam and a Fully Ionized Plasma. Ph.D thesis. (Professor Wharton.)

Wharton, C. B., and Prono, D. 1973. Measurement of ion energy distribution resulting from turbulent heating of plasma. *Plasma Physics* 15:253.

Information and Decision Theory

Studies in the transmission of information focus on source coding problems (such as data compression or redundancy removal for sources such as speech or pictures) and channel coding problems (achieving high rates of reliable communication for such applications as computer-to-computer communication and simultaneous communication). Questions of information processing and utilization arising in the design of radar, sonar, and pattern classification systems (speech recognizers) are subjects for research in decision theory.

New probabilistic coding algorithms are being developed for channels with compound, asynchronous error mechanisms. Rate distortion theory is being used to study the generation of information and the efficiency of information transmission by analog, digital, and biochemical communication systems. Recent problems in simultaneous communications over information nets have opened a new area of research.

The concepts of comparative probability and computational-complexity-based probability are being investigated together with studies of their potential for realistic decision making. Novel nonstatistical algorithms for pattern classification are being developed and evaluated.

Professors Berger, Bergmans, Fine, and Jelinek direct work on these projects. Examples of publications and theses in this area are:

Berger, T. 1971. *Rate distortion theory: A mathematical basis for data compression.* Englewood Cliffs, New Jersey: Prentice-Hall.

Bergmans, P. 1973. Random coding theorem for broadcast channels with degraded components. *IEEE Transactions on Information Theory* IT-19(2):197.

Fine, T. 1973. *Theories of probability: An examination of foundations.* New York: Academic Press.

Jelinek, F. 1973. A two cycle algorithm for source coding with a fidelity criterion. *IEEE Transactions on Information Theory* IT-19(1):77.

Kaplan, M. A. 1974. Extensions and Limits of Comparative Probability Orders. Ph.D. thesis. (Professor Fine.)

Microwave Semiconductor Phenomena and Devices

Research in the field of microwave semiconductor devices emphasizes experimental studies with potential engineering applications. Active elements for the generation and amplification of microwave signals at both low and high power levels, and the use of these elements in such systems as communications links and small radars, are being investigated. The basic physical mechanisms of silicon and compound-semiconductor IMPATT, TRAPATT, Gunn Effect and LSA devices, as well as field-effect transistors, and the use of these devices in microwave integrated circuits, are studied.

Basic materials research involves studying the manipulation of band structure with the aim of discovering new mechanisms of negative differential conductivity; the growth of indium phosphide and gallium arsenide; and the fabrication of useful devices using multiple epitaxy, diffusion, and ion implantation. High speed logic circuits, electrical noise, and the development of methods for characterizing the electrical properties of the active elements and their circuits are also investigated.

Professors Dalman, Eastman, Frey, and Lee are directing this research, which is represented by the following graduate theses and publications:

Camp, W. O., Jr. 1971. Optimum Circuits for GaAs Oscillators: A Theoretical and Experimental Study of Device-Circuit Interaction and Maximum Limits of Operation. Ph.D. thesis. (Professor Eastman.) Results of this research were incorporated into the publication: Camp, W. O., Jr.; Woodard, D. W.; and Eastman, L. F. 1973. Bias tuneable C. W. transferred electron oscillators. In *Proceedings of the Cornell conference on microwave semiconductor devices, circuits, and applications.* Ithaca: Cornell University.

Dalman, G. C.; Zappert, F. G.; and Lee, C. A. 1972. Relaxing-avalanche-mode reflection amplifier. *Electronics Letters* 8(9):243.

Dawson, R. H. Relative Capabilities of Si and GaAs Microwave Field-Effect Transistors. Ph.D. thesis in progress. (Professor Frey.)

Johnson, N. O. 1973. GaAs Schottky Barrier Avalanche Diodes. Ph.D. thesis. (Professor Dalman.)

Kwan, F. S.-C. 1974. A Theoretical and an Experimental Investigation of Superlattice Effects in Semiconductors. Ph.D. thesis. (Professor Lee.)

Lee, C. A., and Frey, J. 1973. Comparison of plasma formation in N^+P and P^+N TRAPATT diodes. *Electronics Letters* 9(14):318.

Network and System Design

Problems of current interest in this area are concerned primarily with computer-aided circuit design, digital filters, nonlinear systems, systems with distributed parameters, and active networks. Both linear lumped networks and active electronic circuits, including integrated circuits, are designed with the aid of computers. Research is being done in the theory and design of broadband active systems, including microwave circuits containing solid state devices such as avalanche diodes, Gunn and LSA oscillators and amplifiers, and transistors.

The synthesis of networks with time-varying and distributed parameters is being investigaged. Gain-bandwidth theory, broad band and highly selective narrow band filters, lump loaded transmission line structures, and time-varying circuits such as n-path filters are among the topics under study.

The CORNAP computer program, which was developed at Cornell, is widely used in industry and at other universities to analyze complicated active linear networks using a state-space approach. The methods used in this program are currently being extended to nonlinear and time-varying networks and distributed parameter systems, with particular emphasis on design optimization methods and the exploitation of sparsity in the matrices defining a complicated network.

Professors Carlin, Ku, Pottle, and Szentirmai are working in these research areas. Recent theses and publications include:

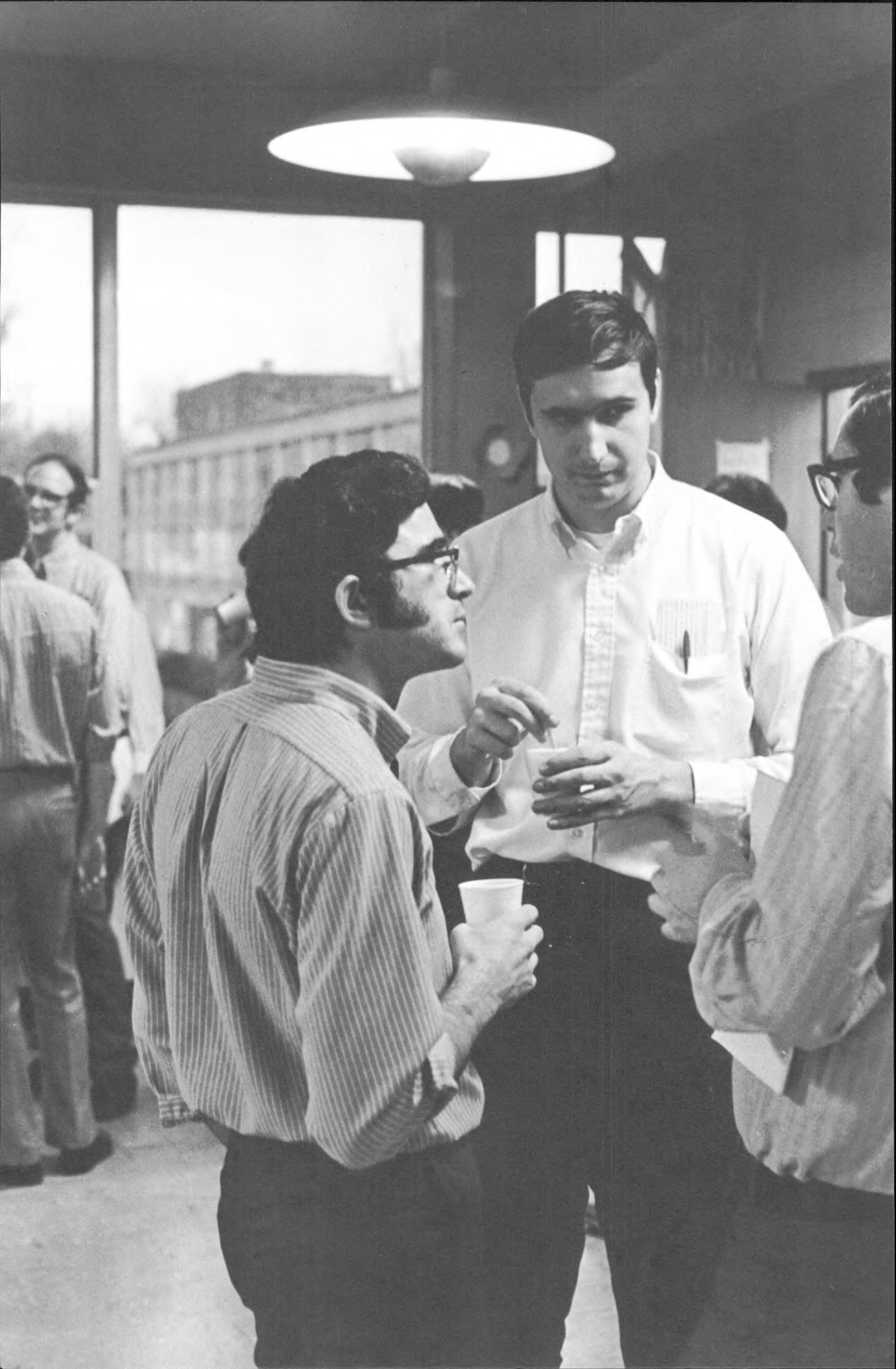
Carlin, H. J. 1973. A simplified circuit model for microstrip. *IEEE Transactions on Microwave Theory and Techniques* MIT-21(9):589.

Kongelbeck, K. S. 1971. The Analysis and Synthesis of Modulation Filters. Ph.D. thesis. (Professor Szentirmai.) A publication resulting from this work is: Kongelbeck, K., and Szentirmai, G. 1972. Synthesis of modulation filters. *IEEE Transactions on Circuit Theory* CT-19:151.

Kotiveeriah, P. 1972. Rational Approximation of Frequency Data by Physically Realizable Network Functions. Ph.D. thesis. (Professor Carlin.)

Norin, R. S. 1970. Rapid Network Analysis Using Sparse Matrix Techniques. Ph.D. thesis. (Professor Pottle.) A paper based on this research appeared as: Norin, R. S., and Pottle, C. 1971. Effective ordering of sparse matrices arising from nonlinear networks. *IEEE Transactions on Circuit Theory* CT-18:139.

Petersen, W. C. 1973. A Design Theory for High Power Broadband Transistor Amplifiers. Ph.D. thesis. (Professor Ku.) A paper based on this research was subsequently presented at a profesfesional meeting: Ku, W. H., and Peterson, W. C. 1973. Analytical and Computer-Aided Design of Broadband Bipolar and FET Transistor Amplifiers. Paper read at 7th Asilomar Conference on Circuits, Systems, and Computers, 27-29 November 1973, in Pacific Grove, California.



Power and Energy Systems

The problems associated with the national energy crisis have stimulated research in areas of related interest. For the past several years, energy research by members of the School of Electrical Engineering has been centered in cooperative efforts within interdisciplinary groups or centers such as Cornell's Laboratory of Plasma Studies and the Cornell Energy Project. While activities in these areas of broad interest are continuing, investigations are being initiated in topics that are of specific interest to electrical engineers.

In the general field of power system network analysis, research is being conducted on the application of control theory and computer-science techniques to the transient stability problem that exists following a major power-system disturbance. Control mechanisms such as dynamic braking, capacitor switching, and governor and exciter regulation are being investigated. An integral part of these studies is concerned with the development of algorithms to provide on-line decisions for optimal coordinated application of the various control mechanisms. Professors Linke, Pottle, Thomas, and Thorp are conducting research in this area of power-system control.

In the field of high-voltage breakdown and dielectric phenomena, research techniques and instrumentation that have been developed in the Laboratory of Plasma Studies are being directed toward planned investigations of insulation behavior at cryogenic and superconducting temperatures, and in studies of switching phenomena. Professors Linke, Nation, and Wharton are directing this research.

Recent theses and publications in the area of power and energy systems include:

Clark, J. J. 1969. Operational Characteristics and Entrance Conditions of a High-Current, Relativistic Electron Beam Accelerator. Ph.D. thesis. (Professor Linke.) A journal publication based on this research is: Clark, J. J., and Linke, S. 1971. Operating modes of a pulsed 50-gigawatt diode. *IEEE Transactions on Electron Devices* ED-18:322.

Thomas, R. J.; Bernard, R. D.; and Meisel, J. 1971. The generation of quasi steady state load flow trajectories and multiple singular point solutions. *IEEE Transactions on Power Apparatus and Systems* PAS-90:1967.

Quantum Electronics and Solid State Physics

Several distinct programs in these areas include research on chemical and molecular lasers, active devices for integrated optics, nonlinear optics, and optical properties of insulators and semiconductors.

In the chemical and molecular laser field, research oriented toward the discovery and study of new laser systems is in progress. The relaxation of vibrational excitation in molecules through atomic and molecular collisions is being studied over an extremely wide range of experimental parameters. Tunable infrared lasers with planned application to tunable laser spectroscopy are being developed. This work is interdisciplinary, with joint participation of faculty members and students in the graduate Fields of Electrical Engineering, Chemistry, and Aerospace Engineering.

Nonlinear optics is a relatively new field of research that became important with the advent of lasers. With the availability of such intense light sources, the nonlinear optical properties of solids, liquids, and gases have become accessible to detailed experimental study; for example, the corresponding nonlinear susceptibilities of many crystals have now been measured. The information obtained has led to an improved understanding of these materials and to an increasing number of applications of technological importance, such as in harmonic generators, tunable optical oscillators, and frequency shifters. Nonlinear optical materials such as III-V, II-VI, and II-IV-V_2 semiconductors and nonlinear optical devices are being studied. Also under study are high power tunable dye lasers that can be used to investigate nonlinear optical effects and other related phenomena.

In the optoelectronics area, programs are underway to develop nonlinear and active thin-film devices that are compatible with integrated optical systems. New thin-film lasers, harmonic generators and tunable oscillators which utilize the advantages of periodic structures and optical waveguides to provide previously unattainable performance are under development. The growth of semiconductor materials for active optical devices is being studied. Related research on materials for active thin-film optical devices centers on electroluminescent Metal-Insulator-Semiconductor structures, with the objective of obtaining basic information on recombination mechanisms, interface states, barrier energies, and current transport. Properties of constituents and interfaces are determined through measurements of cathodoluminescence, electrical photoexcitation, and electroluminescence.

Faculty members involved in these various research efforts are Professors Ballantyne, McFarlane, Nation, Tang, and Wolga. Among recent theses and journal publication in this area are:

Anderson, R. S. 1972. Laser Motivated Studies of Chemiluminescence in Metal Oxides and Nitrides. Ph.D. thesis. (Professor Wolga.)

Ballantyne, J. M. 1972. Effect of phonon energy loss on photoemissive yield near threshold. *Physical Review B* 6:1436.

Campillo, A. J., and Tang, C. L. 1971. Extending the tuning range of tunable oscillators. *Applied Physics Letters* 19:36.

Liu, Y.S.; McFarlane, R. A.; and Wolga, G. J. 1972. Totally inverted vibrational population of CO formed in the reaction of oxygen with acetylene. *Chemical Physics Letters* 14(5):559.

Turner, J. J.; Chen, B.; Yang, L.; Ballantyne, J. M.; and Tang, C. L. 1973. Gratings for integrated optics fabricated by electron microscope. *Applied Physics Letters* 23:333.

Each week a seminar, usually with a visiting scientist as speaker, is held at the School of Electrical Engineering.

Radiophysics and Geophysical Plasmas

Research in this area is concerned with a variety of electromagnetic-wave-propagation phenomena and their utilization in studies of the properties of geophysical plasmas and the neutral atmosphere.

Current topics of study include the interaction of waves and particles in the earth's magnetosphere (VLF emissions), theoretical models of planetary magnetospheres, plasma instabilities occurring in the earth's magnetosphere and ionosphere, the scattering of electromagnetic waves owing to the random fluctuations in density present in a stable plasma such as the ionosphere, and the use of such scatter measurements as a diagnostic tool to study the physical properties and behavior of the ionosphere. Much of this work utilizes data from the giant radar installation (which has an antenna diameter of 1,000 feet and transmitting power of 2.5 megawatts) that is operated by Cornell in Arecibo, Puerto Rico. This radar allows the rapid measurement of many important parameters of the ionosphere over an altitude range of more than 1,000 kilometers. Research is also performed at a similar radar installation near Lima, Peru. Some research in the systems area is devoted to devising efficient digital techniques for handling the vast quantities of data which such radar measurements can produce.

Other research is concerned with the microstructure of the neutral atmosphere (particularly the troposphere, stratosphere, and mesosphere), the fluid mechanical aspects of such structure, and the measurement of this structure by electromagnetic wave techniques.

Professors Bolgiano, Farley, Ott, and Sudan are involved in these research efforts. Recent theses and papers in this area include:

Bolgiano, R., Jr. 1973. Turbulent Transport and Refractive Index Structure Immediately Above the Air-Sea Interface. Paper presented at NATO Advanced Study Institute on Modern Topics in Wave Propagation Above 10 Ghz, Especially Those Associated with Air-Sea Interaction, 5–14 June 1973, in Sorrento, Italy.

Hagen, J. B. 1973. A Hybrid Autocorrelator and its Application to High Altitude Incoherent Scatter. Ph.D. thesis. (Professor Farley.) This thesis research was the basis for a recent journal publication: Hagen, J. B., and Farley, D. T. 1973. Digital correlation techniques in radio science. *Radio Science* 8:775.

McDonough, T. R. 1973. The Solar Wind, the Interstellar Medium and Jupiter. Ph.D. thesis. (Professor Brice.) A publication resulting from this work is: Brice, N., and McDonough, T. 1973. Jupiter's radiation belts. *Icarus* 18:206.

Engineering Design Projects

Students in the Master of Engineering (Electrical) degree program complete a design project as part of the requirements for the degree. Many of these projects are associated with the design of an efficient electric vehicle, prototypes of which have competed in clean air races, and with the design of a roving vehicle for unmanned exploration of Mars.

Faculty Members and Their Research Interests

Paul D. Ankrum, M.S. (Cornell): *solid state devices; power electronics*

Joseph M. Ballantyne, Ph.D. (M.I.T.): *optoelectronic materials and devices; integrated optics*

Toby Berger, Ph.D. (Harvard): *information processing; communication theory*

Patrick P. Bergmans, Ph.D. (Stanford): *simultaneous communication theory; minicomputer software*

Ralph Bolgiano, Jr., Ph.D. (Cornell): *tropospheric radiophysics; communication theory*

Nelson M. Bryant, M.E.E. (Cornell): *electronic circuits; instrumentation*

Robert R. Capranica, Sc.D. (M.I.T.): *bioelectronics; pattern recognition*

Herbert J. Carlin, Ph.D. (Polytechnic Institute of Brooklyn): *microwave circuits; network theory*

G. Conrad Dalman, D.E.E. (Polytechnic Institute of Brooklyn): *microwave solid state devices and circuits*

Lester F. Eastman, Ph.D. (Cornell): *microwave solid state devices; gallium arsenide techinques*

William H. Erickson, M.S. (Carnegie Institute of Technology): *power engineering; instrumentation*

Donald T. Farley, Ph.D. (Cornell): *ionospheric physics; radio propagation*

Terrence L. Fine, Ph.D. (Harvard): *decision theory; pattern classification*

Jeffrey Frey, Ph.D. (California at Berkeley): *microwave solid state devices; integrated electronics*

Frederick Jelinek, Ph.D. (M.I.T.): *coding information theory and speech recognition*

Myunghwan Kim, Ph.D. (Yale): *bioelectronics; control theory*

Walter Ku, Ph.D. (Polytechnic Institute of Brooklyn): *active networks; digital circuits*

Charles A. Lee, Ph.D. (Columbia): *solid state physics and devices*

Richard L. Liboff, Ph.D. (New York University): *plasma physics; electromagnetic theory*

Simpson Linke, M.E.E. (Cornell): *energy systems; high-voltage phenomena*

Ross A. McFarlane, Ph.D. (McGill): *lasers; atomic and molecular spectroscopy*

Henry S. McGaughan, M.E.E. (Cornell): *network and communication theory*

Paul R. McIsaac, Ph.D. (Michigan): *electromagnetic theory; microwave circuits and devices*

John A. Nation, Ph.D. (Imperial College, London): *plasma physics; high-energy electron beams*

Benjamin Nichols, Ph.D. (University of Alaska): *educational techniques*

Robert E. Osborn, B.S.E.E. (Purdue): *electrical machinery; instrumentation*

Edward Ott, Ph.D. (Polytechnic Institute of Brooklyn): *plasma and ionospheric physics*

Christopher Pottle, Ph.D. (Illinois): *computer-aided design; network theory*

Joseph L. Rosson, M.E.E. (Cornell): *power engineering; instrumentation*

Howard G. Smith, Ph.D. (Cornell): *communications; electromagnetic theory*

Ravindra N. Sudan, Ph.D. (University of London): *plasma physics; electromagnetic waves*

George Szentirmai, Ph.D. (Polytechnic Institute of Brooklyn): *computer-aided design; network theory*

Chang L. Tang, Ph.D. (Harvard): *lasers; quantum electronics*

Robert J. Thomas, Ph.D. (Wayne State): *applications of control theory to power systems*

James S. Thorp, Ph.D. (Cornell): *optimization and control theory*

Hwa-Chung Torng, Ph.D. (Cornell): *computer design and architecture; switching theory*

Norman M. Vrana, M.E.E. (Cornell): *switching theory; hybrid computing systems; digital system design and architecture*

Charles B. Wharton, M.S. (California at Berkeley): *plasma physics; microwave diagnostics*

George J. Wolga, Ph.D. (M.I.T.): *lasers; atomic physics*

Further Information

Members of the faculty welcome inquiries about the various graduate programs and research projects. These may be addressed to: Graduate Field Representative, Electrical Engineering, Phillips Hall, Cornell University, Ithaca, New York 14850.

Geological Sciences

Geology, an old science, is currently undergoing a period of major rejuvenation and growth in importance. On the practical side, rapidly increasing consumption of the world's mineral and energy resources and powerful demands for an environment of quality have forced society into a position requiring increased dependence upon this time-honored discipline. On the scientific side, the exploration of the moon and planets, and the development of plate tectonics—a new concept which for the first time permits unification and interrelation of geological information on a global scale—are providing major new frontiers that will enliven and expand the science for many decades to come. In keeping with the new emphasis on geology, Cornell has recently expanded its faculty in geological sciences, provided new quarters for the Department, and is otherwise significantly upgrading its facilities and already extensive materials.

The Department of Geological Sciences has eleven faculty members, and the graduate field includes several specialists in other disciplines who maintain an active interest in the problems of geology. There are approximately twenty graduate students, all of whom participate in one or more of the research activities. Programs leading to the degrees of Doctor of Philosophy and Master of Science are available, and major fields of study may be chosen from a wide variety of specialties, including economic geology, engineering geology, environmental geology, general geology, paleontology, stratigraphy, geochemistry, geomorphology, geophysics, geotectonics, structural geology, marine geology, mineralogy, petrology, physical geology, Pleistocene geology, and seismology. In all areas, there is a strong emphasis on the application of the basic sciences to the understanding of the earth and on learning through participation in research projects.

The Field of Geological Sciences seeks graduate students with a variety of interests and backgrounds, for there are many kinds of geologists and many kinds of careers in geology. An earth scientist may be a keen observer and hardy outdoorsman who studies the earth in the field, or he may be a theoretician using elegant mathematics on the largest computer. He may be a geophysicist or geochemist using sophisticated instruments of high precision and sensitivity. He may be an environmentalist, or a prospector, or an executive, or a teacher, or a practitioner in any one of many other occupations that require knowledge of geology.

The earth sciences offer opportunities and challenges for talented students of almost any sound technical background. Not only students with conventional undergraduate training in geology are encouraged to apply, but also those who have little or no training in geology but who have good preparation in the basic sciences through undergraduate majors in physics, chemistry, biology, mathematics, or a branch of engineering.

A portable seismograph is an essential instrument for seismographic field studies.

Facilities

Most laboratories, shops, and offices are located in Kimball Hall. The building also houses outstanding collections of minerals, rocks, and fossils, and a large library of seismograms from the World Wide Standardized Seismograph Network and from other stations. A rock preparation laboratory, an instrument shop, darkrooms, an X-ray machine, and a petrographic laboratory are among the facilities. More specialized equipment includes portable seismographs, a gravity meter, tiltmeters, magnetometers, a seismic modeling apparatus, and a large plotter. Additional equipment and facilities of great variety are available in nearby buildings of the University.

For field research projects, there are available sites and programs in Tonga, Fiji, and other parts of the southwest Pacific; Labrador; the northeastern and western United States; the nearby Adirondack region; and the area around Ithaca. Cruises on oceanographic research vessels are frequently available to students. The field projects are varied and expanding, and the outlook global in scope.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Areas of Research

A major theme for much of the research activity is the topic of plate tectonics, the far-reaching new concept that brings together for the first time the observational data of most of the disciplines of geology. This concept is being explored and developed at Cornell through its relation to economic geology, geodesy, geomorphology, gravimetry, paleontology, petroleum geology, petrology, seismology, and stratigraphy, among other specialized fields.

The emphasis on plate tectonics is not to the exclusion of other subjects. There are on-going efforts in mineral and energy resources, environmental geology, and certain aspects of paleontology. Lunar and planetary geology may be studied in conjunction with other groups on the Cornell campus.

Current research projects include studies of deep earthquakes in the Tonga, Fiji, and New Hebrides areas, of sea-level changes in various parts of the Pacific and recent crustal movements there and in many other parts of the world, of ore deposits in Minnesota, of the relation between plate tectonics and ore deposition, of geotectonics on a global scale, of microearthquakes in New Zealand and elsewhere, of fossil animals by new techniques that reveal hitherto undetected anatomy, of the rocks of the sea floor and their deformation in island arcs, and of a variety of topics in environmental, engineering, and other branches of geology. Graduate students participate in these research projects at all levels.

Recent publications of faculty members are an indication of some of the current research interests in the geological sciences at Cornell—interests shared by graduate students who are working with their professors on projects in these and related areas. Among the Field members' publications are the following:

Barazangi, M.; Isacks, B.; Oliver, J.; Dubois, J.; and Pascal, G. 1973. Descent of lithosphere beneath New Hebrides, Tonga-Fiji, and New Zealand: Evidence for detached slabs. *Nature* 242:98.

Bird, J. M. 1972. *Proposed U.S. program for the geodynamics program.* Part II of *Program on eastern North America and the continental interior.* Report for the U.S. Geodynamics Committee, Geophysics Research Board, National Academy of Sciences.

Bloom, A. L., et al. 1972. New uranium-series dates from the emerged reef terraces on Huon Peninsula, New Guinea. In *Abstracts of the 2nd national conference of the American Quaternary Association,* ed. C. Emiliani, p. 11. Miami, Florida: University of Miami.

Bonnichsen, B. 1972. The geologic occurrence of nickel deposits. In *Proceedings of 33rd annual mining symposium.* Duluth: University of Minnesota.

Graduate students who hold teaching assistantships help in undergraduate instruction.

Cisne, J. L. 1973. Life history of an Ordovician Trilobite Triarthrus Eatoni. *Ecology* 54(1):135.

Isacks, B. L., and Barazangi, M. 1973. High frequency shear waves guided by a continuous lithosphere descending beneath western South America. *Geophysical Journal* 33:129.

Karig, D. E., and Mammerickx, J. 1972. Tectonic framework of the New Hebrides Island arc system. *Marine Geology* 12:187.

Kiersch, G. A. 1972. Triassic Basin geologic considerations. Chapter X in *Conceptual analysis report, Savannah River plant bedrock waste storage project,* U.S. Atomic Energy Commission, p. x-1.

Kuckes, A. F. 1973. Correspondence between magnetotelluric and field penetration depth analyses for measuring electric conductivity. *Geophysical Journal* 32:381.

Morrison, G. H. In press. Application of activation analysis to the earth sciences. *Journal of Radioanalytical Chemistry.*

Ruoff, A. L., Lincoln, R. C., and Chen, Y. C. 1973. A new method of absolute high pressure determination. *Journal of Physics D: Applied Physics* 6:1295.

Oliver, J. 1973. Dynamics of the down-going lithosphere. *Tectonophysics* 19:133.

Travers, W. B. 1972. Miocene subduction in northern Italy. In *Proceedings of the international geologic conference,* p. 180. Montreal, Canada: International Geologic Conference.

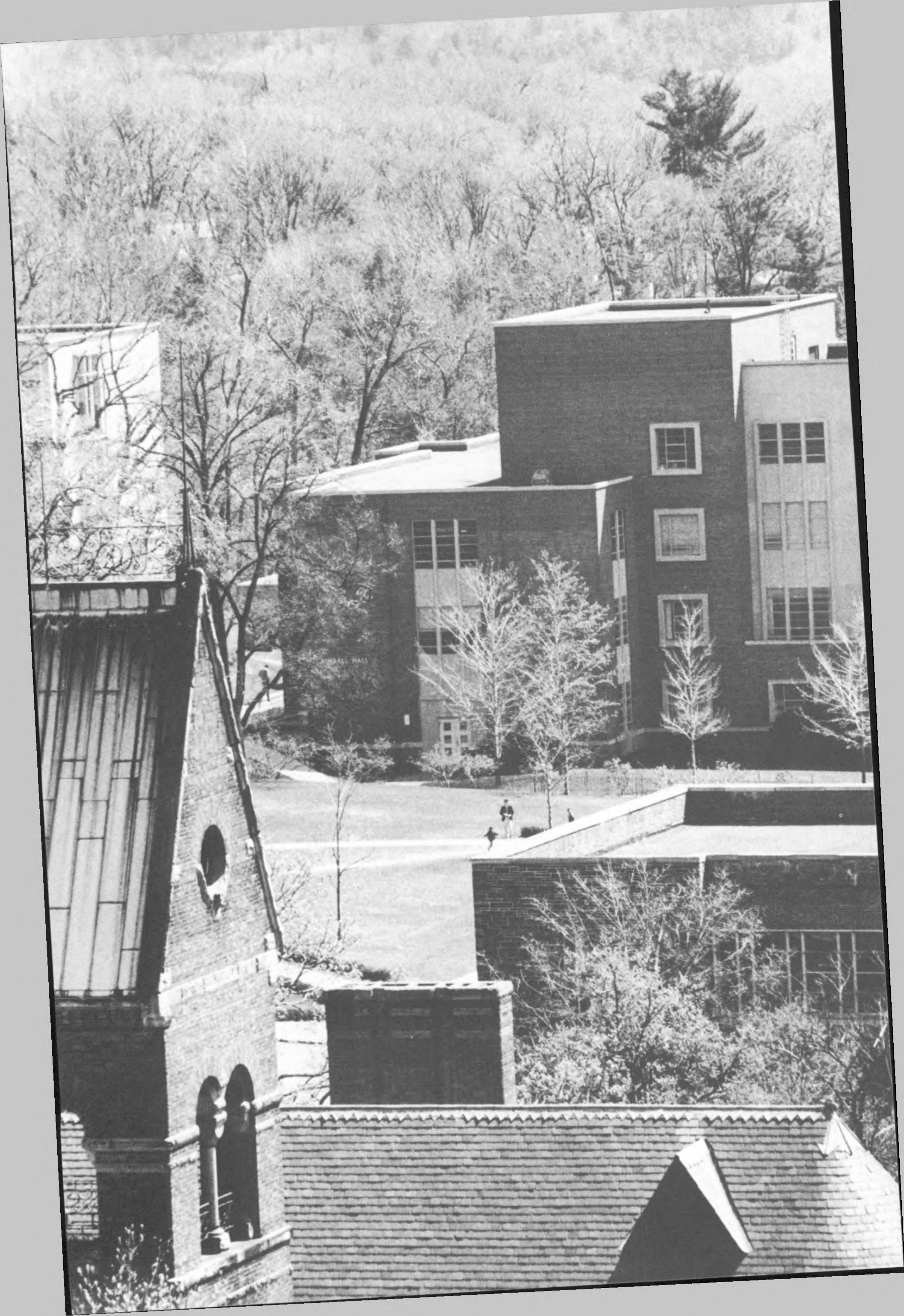
Turcotte, D., and Oxburgh, E. R. 1972. Mantle convection and the new global tectonics. *Annual Review of Fluid Mechanics* 4:33.

Faculty Members and Their Research Interests

Members of the Field of Geological Sciences are listed, along with their specialties and some specific topics that are representative of their current research interests.

John M. Bird, Ph.D. (R.P.I.): *geotectonics; theoretical tectonics; plate tectonics; orogeny.* Petrology and structure of upper mantle rocks; Appalachian geology, particularly of New England and Newfoundland; theoretical petrology of the earth's core; computer graphics, lithosphere plate reconstructions, and reconstructions of ocean floors.

Arthur L. Bloom, Ph.D. (Yale): *geomorphology; Pleistocene geology.* Investigation of raised coral reefs of the Great Barrier Reef of Australia and of related features in other parts of the southwest Pacific to determine the history and glacial control of sea level.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Bill Bonnichsen, Ph.D. (Minnesota): *petrography and petrology; economic geology.* Study of the Duluth Igneous Complex in northeastern Minnesota. (This study involves geologic mapping, petrology, and evaluation of the mineral resources potential of this large area. The complex has an enormous potential for new deposits of copper, nickel, cobalt, the platinum group metals, and titanium. Also, this is one of the few places on earth where a preexisting accretional plate margin (midoceanic type) is well exposed, permitting study of the igneous processes that occurred there.)

John L. Cisne, Ph.D. (Chicago): *invertebrate paleontology; evolutionary biology; population and community paleoecology; stratigraphy.* Studies of the anatomy, functional morphology, and ecology of modern and fossil arthropods as related to problems of the origin of the arthropods, the evolution of like histories and dispersal mechanisms, and evolutionary patterns of ecological specialization and taxonomic diversification.

Bryan L. Isacks, Ph.D. (Columbia): *seismology; tectonics.* Study of the seismic phenomena of island arcs, particularly in the Tonga-Fiji-New Hebrides region of the southwest Pacific, to determine the dynamics and structure of the down-going slab of lithosphere and their relation to global tectonics.

Daniel F. Karig, Ph.D. (Scripps): *marine geology and geophysics; geotectonics.* Synthesis of geological and geophysical information, such as that from the JOIDES deep-sea drilling project, to provide an improved understanding of the formation and evolution of the island arcs of the world.

Sidney Kaufman, Ph.D. (Cornell): *geophysical prospecting.* Use of conventional prospecting techniques on an expanded scale to explore the deeper parts of the crust of the earth.

George A. Kiersch, Ph.D. (Arizona): *engineering geology.* Disposal of radioactive wastes and high-energy materials; environmental and geologic considerations in the siting of nuclear power plants and other major engineering works.

Arthur F. Kuckes, Ph.D. (Harvard): *geophysics; electromagnetic methods.* Studies of the electric conductivity of the earth's mantle and crust.

George H. Morrison, Ph.D. (Princeton): *analytical geochemistry.* Determination of trace element abundances in terrestrial, meteoritic, and lunar materials using spark source mass spectrometry, neutron activation analysis, and atomic spectroscopy.

Jack E. Oliver, Ph.D. (Columbia): *geophysics; geotectonics.* Integration of information from leveling, triangulation, and sea-level measurements, from aerial photography, and from geomorphological and other kinds of geological study, in order to improve understanding of recent crustal movements and hence of earthquakes, particularly those occurring in normally aseismic areas.

Arthur L. Ruoff, Ph.D. (Utah): *properties of materials under high pressure.* Development of multi-megabar static pressure system; sythesis of metallic hydrogen; pressure effects on plastic flow phenomena.

William B. Travers, Ph.D. (Princeton): *structural geology and tectonics; petroleum geology; sedimentology; natural energy resources.* Tectonic evolution of the northern Apennine Mountains in Italy; structural geology of the Snake River Plain in Idaho; early Tertiary structural evolution of the central California coast; structural geology of Barbados; tectonics of central British Columbia.

Donald L. Turcotte, Ph.D. (Cal. Tech.): *geophysical fluid dynamics; mantle convection; geotectonics; thermal problems of the earth.* Calculations of membrane and thermal stresses in the earth's crust and studies of their geological significance.

Further Information

Questions about the expanding graduate program in geological sciences may be addressed to: Graduate Field Representative, Geological Sciences, Kimball Hall, Cornell University, Ithaca, New York 14850.

Research activities in geological sciences are centered in Kimball Hall on the Engineering Quadrangle.

Materials Science and Engineering

The graduate Field of Materials Science and Engineering at Cornell provides students with widely differing undergraduate backgrounds the opportunity to undertake graduate research and study in the area of materials. The forty-five graduate students now in the department have undergraduate degrees in physics, applied physics, and mechanical, metallurgical, chemical, and electrical engineering, as well as in materials science.

Most of the research in the department is conducted in connection with the interdisciplinary Materials Science Center, the largest such university center supported by the federal government. One of the purposes of the Materials Science Center is to support large central facilities (for example, the electron microscope laboratory) which make available to every student and faculty member modern and, often, very expensive equipment. The Center also provides financial assistance for graduate students through research assistantships and equipment for thesis research projects.

In addition to research-oriented M.S. and Ph.D. programs in the graduate Field of Materials Science and Engineering, a professional Master of Engineering (Materials) degree program is available.

Facilities

Laboratories and equipment are located in Bard and Thurston Halls on the engineering campus and in Clark Hall of Science, which houses some of the University's physics groups and most of the Materials Science Center facilities.

The extensive facilities available at Cornell make possible a wide variety of research in materials science. For example, a 50,000-pound electrohydraulic materials testing system enables researchers to test engineering specimens of high-strength materials under various loading conditions, including cyclic loading of any arbitrary wave form. This testing system complements various Instron testing machines to provide a wide range of capability for studying macroscopic mechanical behavior of materials.

An electrohydraulic closed-loop testing machine is adjusted prior to the precision measurement of crack growth in a high-strength steel.

For other types of investigation there are available seven field ion microscopes, seven electron microscopes, high-field magnets, X-ray diffraction equipment, ultrahigh-vacuum apparatus, low-energy-electron-diffraction apparatus, high-pressure systems, ultrasonic equipment, cryostats, a residual gas mass spectrometer, and various pieces of optical and electronic equipment. The properties of materials can be probed down to the atomic scale.

The electron microscopes that graduate students in the Field may use are located in two laboratories. In Clark Hall there are AEI EM 802, Siemens Elmiskop 1A, and Hitachi HU 11A microscopes. In Bard Hall there are JEM 200-kv, Siemens 102, and AEI EM6G microscopes, as well as an AMR 900 scanning electron microscope. These instruments are equipped with special stages, such as two-directional tilting stages, a liquid helium stage, a high-temperature stage, and a tensile straining stage, for various specific applications.

Areas of Research

A wide range of research projects is available to graduate students. Faculty members are continually developing new areas of materials research; for example, during the past two years projects were started on ceramic oxides, amorphous materials, biomaterials, polymers, and laser holography. Some of the current research areas are described briefly below.

Imperfections in Solids

A research group headed by Professor Balluffi is studying quenched-in vacancies in tungsten by combined field ion microscopy and low-temperature electrical resistivity. The spatial distribution of solute atoms in dilute platinum-base alloys is also being studied by field ion microscopy. In this work, the lattice position of each solute atom is determined and computer techniques are employed to determine the radial distribution function. In addition, diffusion rates along dislocations and grain boundaries are being studied in thin film specimens. The defect structure is first determined by transmission electron microscopy, and then the diffusion rates of atoms along these defects are studied by means of an Auger spectroscopy technique.

In an extensive research program supervised by Professor Seidman, point defects and their interactions in irradiated metals are being studied by means of field ion microscopy. The field ion microscope (FIM), with its atomic resolution, allows the direct observation of individual atoms in the perfect crystal lattice, as well as self-interstitial atoms and vacant lattice sites. In addition to the conventional FIM, the group is using an atom-probe FIM which it recently constructed. This instrument allows the determination of the charge-to-mass ratio of a single preselected atom, which appears in the FIM image. Since the operation of the atom-probe FIM is controlled by a Nova 1220 computer, it is possible to gather and analyze a statistically significant quantity of data in a relatively short period of time. The atom-probe FIM is being used to study the interaction between solute atoms and both radiation-induced vacancies and self-interstitial atoms. In some recently completed studies, the point defect structure of irradiated tungsten has been elucidated, and evidence of long-range migration of self-interstitial atoms in tungsten and platinum has been provided by in situ FIM experiments.

Professor Li and his group are investigating metal swelling caused by void formation, which results from fast neutron irradiation. These studies are relevant to the development of liquid metal fast breeder reactors and of projected controlled thermal nuclear reactors.

Work with highly perfect crystals is proceeding under the supervision of Professor Batterman. With the use of these crystals, internal X-ray crystal interferences can be observed, and the technique is being used to obtain independent measurements of the atomic form factors of elements which can form structurally perfect crystals. In recent dynamical diffraction studies, an experiment was devised by which the site of an impurity atom in a host lattice could be determined. Experiments underway are designed to determine the sites of ions implanted by particle accelerators in silicon; the pertinence of this investigation lies in the fact that controlled doping of large-scale integrated circuits is accomplished by ion implantation. Thermal scattering of X-rays and neutrons is being used to measure frequency as a function of wave number of phonons in a lattice.

In research directed by Professor Sass, a new technique developed at Cornell is being used to determine directly the core structure of screw dislocations. The method is based on the observation that periodic arrays of dislocations diffract (i.e., give rise to extra reflections). Theoretical calculations have shown that the structure factor of such an array is quite sensitive to the core configuration. In principle, if the intensities of the extra reflections can be measured, it will be possible to determine directly the location of the core atoms. The X-ray experiments involved in this research are being carried out in collaboration with Professor Batterman.

Recent publications in the area of imperfections in solids include:

Berger, A. S.; Seidman, D. N.; and Balluffi, R. W. 1973. A quantitative study of vacancy defects in quenched platinum by field ion microscopy and electrical resistivity. *Acta Metallurgica* 21:123.

Guan, D. Y., and Sass, S. L. 1973. Diffraction from periodic arrays of dislocations. I. The structure factor of a square grid of screw dislocations in a low-angle (001) twist boundary. II. A possible method for the direct determination of the core structure of screw dislocations. *Philosophical Magazine* 27:1211, 1225.

Harkness, S. D., and Li, C.-Y. 1971. A study of void formation in fast neutron-irradiated metals. *Metallurgical Transactions* 2:1457.

Keating, D.; Nunes, A.; Batterman, B.; and Hastings, J. 1971. Anharmonicity and the temperature dependence of the forbidden (222) reflection in silicon. *Physical Review Letters* 27:320.

Park, J. Y.; Huang, H.-C. W.; Berger, A. S.; and Balluffi, R. W. 1973. Study of vacancy defects in quenched tungsten by combined electrical resistivity and field ion microscopy. In *Proceedings of the conference on defects and defect clusters in B.C.C. metals and their alloys*, p. 470. Washington, D.C.: National Bureau of Standards.

Seidman, D. N. 1973. The direct observation of point defects in irradiated or quenched metals by quantitative field ion microscopy. *Journal of Physics F: Metal Physics* 3:393.

Examples of doctoral theses in this area of study are:

Berger, A. S. 1971. A Quantitative Study of Point Defects in Platinum by Field Ion Microscopy and Electrical Resistivity. Ph.D. thesis. (Professor Balluffi.).

Chen, Y.-C. 1971. On the Atomic Resolution and the Field Ionization Characteristics of a Field Ion Microscope. Ph.D. thesis. (Professor Seidman.)

Scanlan, R. M. 1971. An In-Situ Field Ion Microscope Study of Stage I Recovery in Tungsten Irradiated with 20 keV W Ions. Ph.D. thesis. (Professor Seidman.)

Surfaces and Interfaces

In a project directed by Professor Balluffi, a technique has been developed for producing any type of planar grain boundary in thin film bicrystal specimens under controlled conditions. Studies of the structure of grain boundaries are being made with use of high-resolution electron microscopy. Professors Balluffi and Sass are collaborating in the development and use of diffraction techniques to study the periodic structure of grain boundaries.

Studies by Professor Blakely and his students are concerned with surface phenomena in crystalline solids. Optical diffraction and interference measurements, developed for a study of the mass transport processes that occur in crystalline solids at high temperatures, are yielding information on surface diffusion, volume diffusion, and surface energies. The technique of Auger electron spectroscopy is being used for chemical analysis in studying the phenomenon of solute segregation to free surfaces. Other surface phenomena, such as the variation of electronic work function with surface structure and with adsorption, order-disorder transformations, and oxide growth on the basal planes of the group II hexagonal metals, are being studied with use of low-energy electron diffraction (LEED) and dynamic capacitor techniques. Defects occurring near the free surfaces of ionic crystals are also being studied theoretically and experimentally.

The coupled diffusion problem associated with Ostwald ripening has been analyzed by Professor Li, and this analysis is being applied to the aging process and thermal stability of dispersed systems. In another project, the structure and mechanical behavior (deformation, fracture, and fatigue) of grain boundaries are being investigated by transmission electron microscopy and Auger spectroscopy.

Typical of the publications in this area are:

Baker, J. M., and Blakely, J. M. 1972. A study of LEED intensities from cleaved beryllium and zinc surfaces. *Surface Science* 32:45.

Feingold, A. H., and Li, C.-Y. 1968. Experimental verification of mass transport analysis for Ostwald ripening and related phenomena. *Acta Metallurgica* 16:1101.

Hirth, J. P., and Balluffi, R. W. 1973. On grain boundary dislocations and ledges. *Acta Metallurgica* 21:929.

Some recent doctoral research in this area resulted in the following theses:

Matysik, K. J. 1973. A Study of RHEED Intensities from Oxygen and Hydrogen (2 x 1) Surface Structures in W(110). Ph.D. thesis. (Professor Batterman.)

Olson, D. L. 1970. Surface Self-Diffusion of Gold. Ph.D. thesis. (Professor Blakely.)

Shelton, J. C., III. 1973. Equilibrium Carbon Segregation to a Nickel (III) Surface: A Surface Phase Transformation. Ph.D. thesis. (Professor Blakely.)

Mechanical Behavior of Materials

The relationships among cyclic deformation parameters, fatigue, and lattice defects are being studied in high-purity copper and aluminum by Professor Johnson and his students. Another research program under the guidance of Professor Johnson is concerned with the effects of different aggressive and innocuous environments on the fracture behavior of high-strength steels.

In the area of polymers, Professor Kramer and his group are working on the identification of mechanisms responsible for crazing, fracture, and plastic deformation of polymers at and below the glass transition. Small-angle X-ray scattering (SAXS) as well as optical techniques such as Moiré analysis, light scattering, and birefringence measurements are important tools for this study. Professors Ast and Kramer and their students are collaborating on a project in which holographic interferometry is used to map strain fields in the vicinity of crazes and cracks. Professor Ast is especially interested in developing holographic interferometry of very small areas.

Professors Ast and Kramer are also working, as part of a larger College of Engineering and Cornell Medical College team, to elucidate the structure of reconstituted collagen, which can be used for such applications as artificial kidney dialysis membranes and drug-delivery systems. Here, SAXS as well as differential scanning colorimetry and infrared absorption measurements give important clues to collagen structure.

The design of advanced power generation systems requires better descriptions of the mechanical behavior of solids at elevated temperatures over long periods of time, and Professor Li and his students are performing pertinent creep and stress relaxation experiments.

Professor Ho's group is applying various techniques in laser holographic interferometry to study micromechanics in composite materials. Research areas that are being pursued include stress analysis in the elastic-plastic region, in situ observation of the initiation and growth of cracks at fiber-matrix interfaces, and stress determination in composite materials under harmonic loads.

Representative of the papers written by Cornell researchers in this area are:

Johnson, H. H., and Paris, P. C. 1968. Subcritical flaw growth. *Engineering Fracture Mechanics* 1:1.

Lin, W., and Kramer, E. J. 1973. Small angle X-ray scattering from amorphous polycarbonates. *Journal of Applied Physics* 41:4327.

Yaggel, F. L., and Li, C.-Y. 1971. *Failure mechanisms for internally pressurized thin-wall tubes and their relationship to fuel element failure criteria.* Argonne National Laboratory Report no. 7805.

Among recent theses on these subjects are:

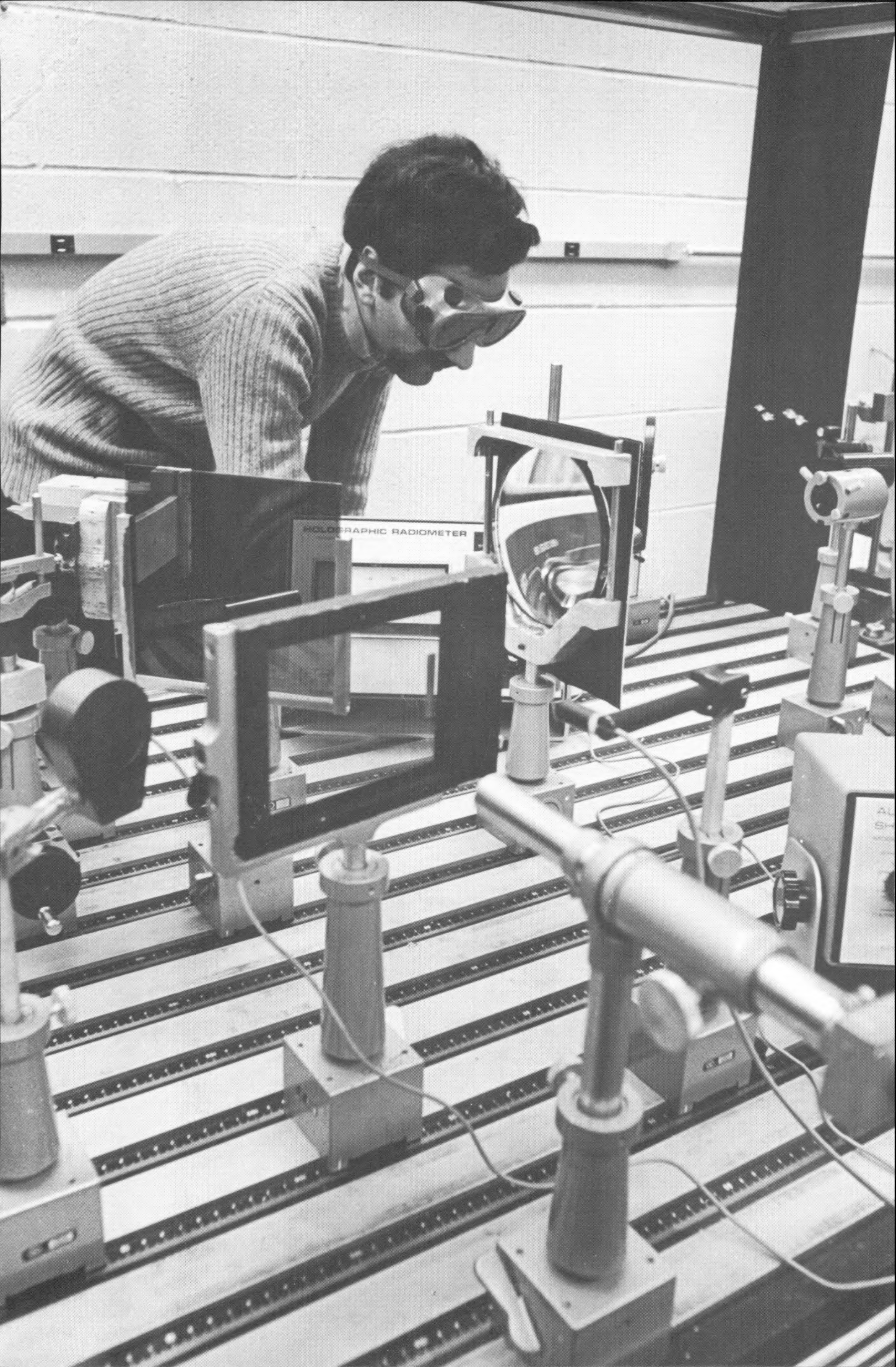
Mandigo, F. N. 1973. Cyclic Deformation and Defects in High Purity Copper. Ph.D. thesis. (Professor Johnson.)

Thomas, E. L. 1974. The Defect Structure of Polyethelene Single Crystals. Ph.D. thesis. (Professor Sass.)

Sawicki, V. R. 1971. Hydrogen Induced Cracking in a High Strength Steel. Ph.D. thesis. (Professor Johnson.)

High-Pressure Studies

The research program on materials under high pressure is under the direction of Professor Ruoff. One current project is a study of the mechanism of creep through measurements of its pressure dependence and the effect of doping. Other studies are concerned with the effect of hydrostatic pressure dependence of the yield stress and the stress-strain


HOLOGRAPHIC RADIOMETER

curve for metals. Ultrasonic interferometry and continuous wave techinques are being used to measure the elastic constants of solids, data which are useful in many theoretical and experimental studies. The forming of materials by hydrostatic extrusion promises to be an important commercial process, and investigations are under way to develop techniques of continuous extrusion.

Isostatic compaction of ultrafine particles of tantalum carbide and tungsten carbide is being carried out under special conditions with the intention of producing extremely fine-grained materials (0.03-0.1μ).

Ultrahigh-pressure work now being conducted has as its goal the production of new synthetic polymorphs (metallic NH_4, metallic hydrogen, and CO_2 with a three-dimensional network.) Metallic hydrogen, for example, is a high-pressure form of the gas which may be metastable at atmospheric pressure. In connection with these experiments, it is hoped to generate static pressure in excess of two million atmospheres, which approaches the pressure at Earth's center.

A few of the recent publications in this area are:

Larsen, R. E., and Ruoff, A. L. 1973. Pressure-induced elasticity changes in V_3Si. *Journal of Applied Physics* 44:1021.

Ruoff, A. L.; Lincoln, R. C.; and Chen, Y. C. 1973. A new method of absolute high pressure determination. *Journal of Physics D: Applied Physics* 6:1295.

Ruoff, A. L. 1973. Penultimate static pressure containment considerations and possible applications to metallic hydrogen preparation. *Advances in Cryogenic Engineering* 18:435.

Recent thesis work in this area includes:

Day, J. P. 1973. The Variation of the Elastic Constants of Lithium with Temperature and Pressure. Ph.D. thesis. (Professor Ruoff.)

Larson, R. 1973. Influence of Hydrostatic Pressure Loading on the Elasticity of the A-15 Superconductor V_3Si. Ph.D. thesis. (Professor Ruoff.)

Lincoln, R. C. 1971. A Device for Length and Other Thermodynamic Measurements at High Pressure. Ph.D. thesis. (Professor Ruoff.)

Phase Transformations

Researchers headed by Professor Sass are studying the omega phase transformation that occurs in titanium and zirconium alloys and has an important effect on their mechanical and superconducting properties. Direct lattice imaging, high-resolution dark-field electron microscopy, and electron diffraction are being used to study the local structure of these alloys before transformation, as well as the mechanism of transformation. In order to understand the influence of the omega phase on the mechanical properties, single-crystal studies of the deformation structures in these alloys have been conducted.

A new technique developed by Professor Batterman's group makes use of the Mössbauer effect to study the dynamics of phase transformations. Mössbauer gamma rays scattered from crystals can be separated into elastic and inelastic components, and these can be related to the dynamical aspects of the omega-phase transition.

Professor Batterman and Professor Sass are using optical and electron microscopy, as well as X-ray and electron diffraction, to study phase transformations and the ordering of hydrogen in vanadium-hydrogen and tantalum-hydrogen systems.

Ceramic oxides such as iron aluminate spinels (a catalyst for direct ammonia synthesis) and tellurium dioxide (an acousto-optical beam deflector) are being investigated by Professor DeJonghe and his students. The spinel single crystals are fabricated by a chemical vapor reaction technique. Cation-anion nonstoichiometry can be produced in these oxides by heating in a controlled oxygen atmosphere or by direct cation or anion implantation. The transient phase transformations and defect structures that result from such treatments are studied by means of transmission and scanning electron microscopy, as well as by X-ray diffraction and optical microscopy.

Some representative publications in this area of research are:

Batterman, B. W.; Maracci, G.; Merlini, A.; and Pace, S. 1973. Diffuse Mössbauer scattering applied to dynamics of phase transformations. *Physical Review Letters* 31:227.

DeJonghe, L. C., and Thomas, G. 1971. High voltage electron microscopy of phase transformations in cobalt ferrites. *Materials Science and Engineering* 8:259.

Sass, S. L. 1972. The structure and decomposition of Zr and Ti b.c.c. solid solutions. *Journal of Less Common Metals* 28:157.

Wanagel, J.; Sass, S. L; and Batterman, B. W. 1974. Observations on the microstructure and orientation relations in the vanadium-hydrogen system. *Metallurgical Transactions* (in press).

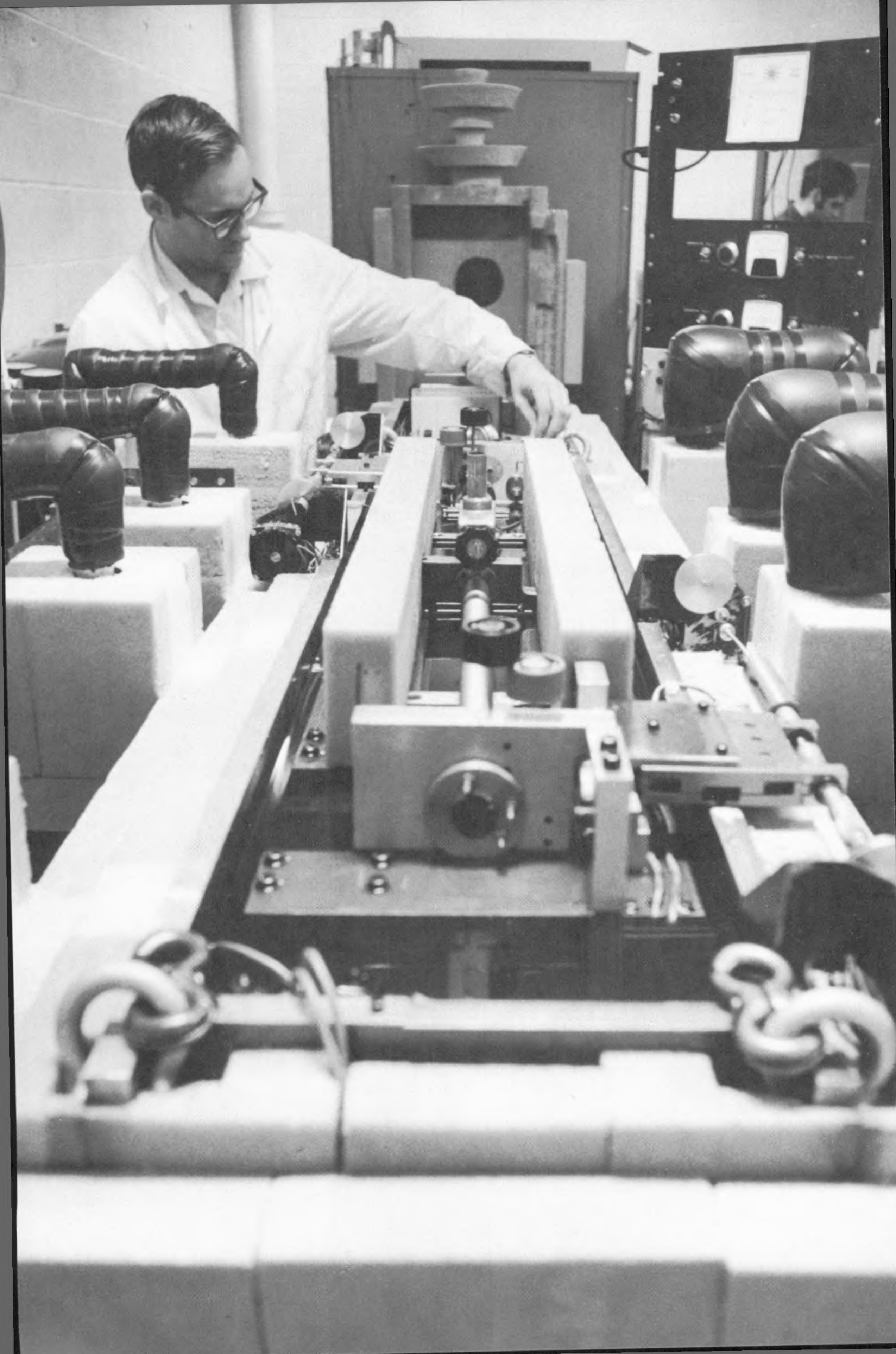
Recent graduate theses written on some of these subjects include:

Goasdoue, C. 1971. Study of the $\beta \rightarrow \omega$ Phase Transformation in Zr-Nb Alloys by Elastic Constant Measurements. M.S. thesis. (Professor Sass.)

Ahrens, R. R. 1973. Deformation Structures in B.C.C. Ti-V Single Crystals Containing the Omega Phase. M.S. thesis. (Professor Sass.)

Wanagel, J. 1972. A Study of Hydrogen in Vanadium. Ph.D. thesis. (Professor Batterman.)

Double exposure holography is used in studies of cracks and crazes in polymers and cracks in metals.



Electrical and Magnetic Properties

A study of the electronic conductivity of As_xTe_{1-x} films as a function of composition is supervised by Professor Ast. Percolation theory in connection with a bond picture is being applied to explain the results. The structure of amorphous As-VI compounds is being studied with use of diffraction as well as indirect methods based on known relations between the glass transition temperature, the viscosity, and the molecular weight of chain polymers.

Professors Ast and Ruoff head a joint project to produce multilayered composite superconductors with very fine lamellar spacings (of the order of Angstroms) by controlled vapor deposition. The goal is to produce a structure in which flux lines are pinned very effectively, and thereby to obtain superconductors with high critical fields and low AC losses.

Experimental and theoretical work under the supervision of Professor Ho is concerned with the effects on metals of potential and thermal gradients and of ion bombardment. These studies are of interest in electronics because it is known that void formation induced by electromigration in metallic films is an important failure mode of microelectronic devices. They are important to studies of metals exposed to neutron irradiation because pore formation under ion bombardment causes swelling of the metal and consequent structural damage. The research effort utilizes transmission and scanning microscopy and laser interferometry.

An understanding of the mechanisms of pinning of the flux line lattice by crystal defects, such as dislocations or surfaces, is basic to the production of superconducting wire with a high critical current. The objective of work under the direction of Professor Kramer is to elucidate these mechanisms. Also, the pinning due to defects produced by neutron irradiation is being investigated because of its importance in projected controlled nuclear fusion applications of superconductors.

Examples of recent publications in this area are:

Ast, D. G. 1973. Structural and electrical properties of evaporated-amorphous and vitreous-amorphous V-VI compounds. *Journal of Vacuum Science Technology* 10:748.

Ho, P. S., and Glowinski, L. 1970. Observation of electromigration in thin films. In *Proceedings of the international conference on atomic transport in solids and liquids*. Marstrand, Sweden.

Kramer, E. J. 1973. Scaling laws for flux pinning in hard superconductors. *Journal of Applied Physics* 44:1360.

Graduate theses in this field of research include:

Glowinski, L. D. 1972. Study of Electron Damage in Quenched and Helium Pre-Injected Aluminum. M.S. thesis. (Professor Ho.)

Gupta, A. D. 1971. Anisotropy of the Surface Critical Current in Superconducting Niobium Crystals. Ph.D. thesis. (Professor Kramer.)

A laser interferometer is used for equation of state measurements at high pressure.

Putz, A. G. 1972. Flux Motion and Pinning in a Type II Superconductor. M.S. thesis. (Professor Kramer.)

Rickenback, R. 1973. Multi-Layered Thin Film Superconductors. M.S. thesis. (Professors Ast and Ruoff.)

Faculty Members and Their Research Interests

Dieter G. Ast, Ph.D. (Cornell): *amorphous materials; multilayered superconductors; biomaterials; holographic testing*

Robert W. Balluffi, Sc.D. (M.I.T.): *crystal defects; radiation damage; diffusion*

Boris W. Batterman, Ph.D. (M.I.T.): *X-ray and neutron diffraction; solid state phenomena*

John M. Blakely, Ph.D. (Glasgow): *surface physics; point defects; diffraction*

Malcolm S. Burton, S.M. (M.I.T.): *mechanical properties of solids*

Lutgard C. DeJonghe, Ph.D. (California, Berkeley): *ceramic oxides*

Paul S. Ho, Ph.D. (R.P.I.): *electromigration and thermomigration; lattice defects; composite materials*

Herbert H. Johnson, Ph.D. (Case): *dislocation mechanics; gases in metals; cyclic deformation; environment and fracture*

Edward J. Kramer, Ph.D. (Carnegie-Mellon): *superconductivity; mechanical properties; high polymer physics*

Che-Yu Li, Ph.D. (Cornell): *mechanical behavior; surface and interface studies; irradiation effects*

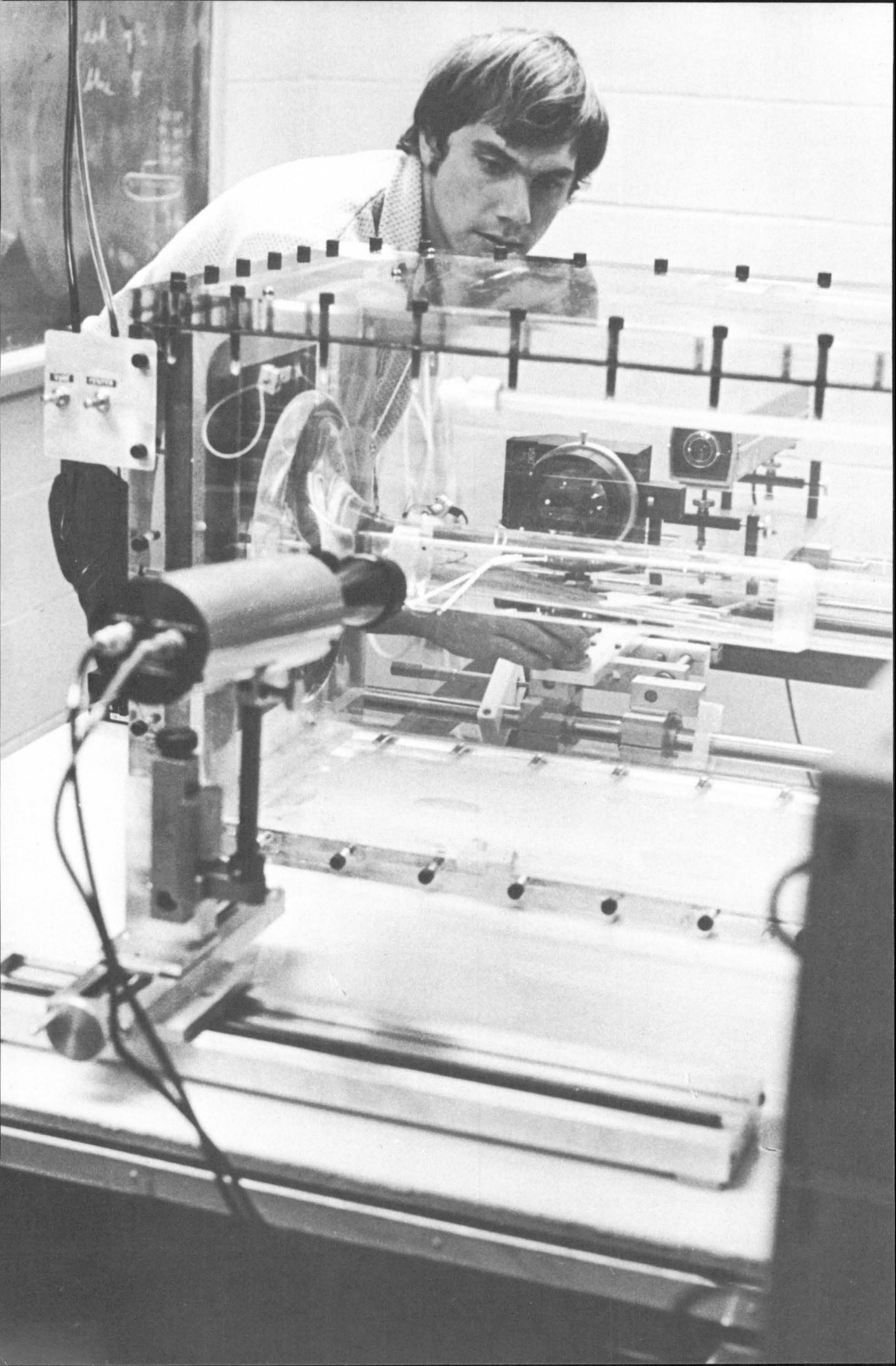
Arthur L. Ruoff, Ph.D. (Utah): *high-pressure phenomena; higher order elastic constants; hydrostatic extrusion; creep*

Stephen L. Sass, Ph.D. (Northwestern): *phase transformations; transmission electron microscopy; diffraction*

David N. Seidman, Ph.D. (Illinois): *lattice defects; radiation damage; field ion microscopy*

Further Information

Inquiries about graduate study in materials science and engineering may be addressed to: Graduate Field Representative, Materials Science and Engineering, Bard Hall, Cornell University, Ithaca, New York 14850.



Mechanical Engineering

The graduate Field of Mechanical Engineering at Cornell offers advanced instruction and research opportunities in a wide variety of topics that have traditionally been part of the professional field of mechanical engineering. The emphasis, however, is on the engineering sciences that are basic to the field and upon research and advanced design and development in those engineering applications that are both recent and of growing importance. Mechanical Engineering at Cornell is closely allied with another graduate Field: Aerospace Engineering. Together they constitute the Sibley School of Mechanical and Aerospace Engineering, which also offers a wide variety of undergraduate courses and an undergraduate field program in mechanical engineering.

Candidates for the M.S. or Ph.D. degrees in mechanical engineering choose a major subject from this Field and a minor subject which is generally from some other field of engineering or other division of the University. Minor subjects commonly chosen include mathematics, nuclear engineering, solid mechanics, fluid mechanics, plasma studies, aerospace engineering, and electrical engineering. The work of an M.S. or Ph.D. candidate is supervised by a Special Committee whose chairman is the professor representing the major subject. He is usually the student's research and thesis adviser as well.

Also offered is a professional graduate program leading to the degree of Master of Engineering (Mechanical). This program is intended primarily for students who are seeking advanced professional training and whose major interests are in design and development rather than research. In addition to his course work, the M.Eng. candidate works on a design project which he chooses. The project is usually a team effort and often is carried out in cooperation with an industrial organization which suggests the problem, participates in its detailed formulation, and reviews the solution upon its completion.

The mechanics of vortex flows are studied experimentally with a laser doppler anemometer.

A weekly colloquium and a weekly research conference, both held jointly with the graduate Field of Aerospace Engineering, help to preserve and encourage an informal relationship between graduate students and faculty. Colloquium speakers are recognized authorities in their fields. Frequently they are former graduate students or faculty members from Cornell or other universities. Graduate students who are engaged in thesis research present progress reports on their work at the research conference and benefit from suggestions offered by other students and faculty members. New graduate students find these conferences helpful in choosing research projects of their own.

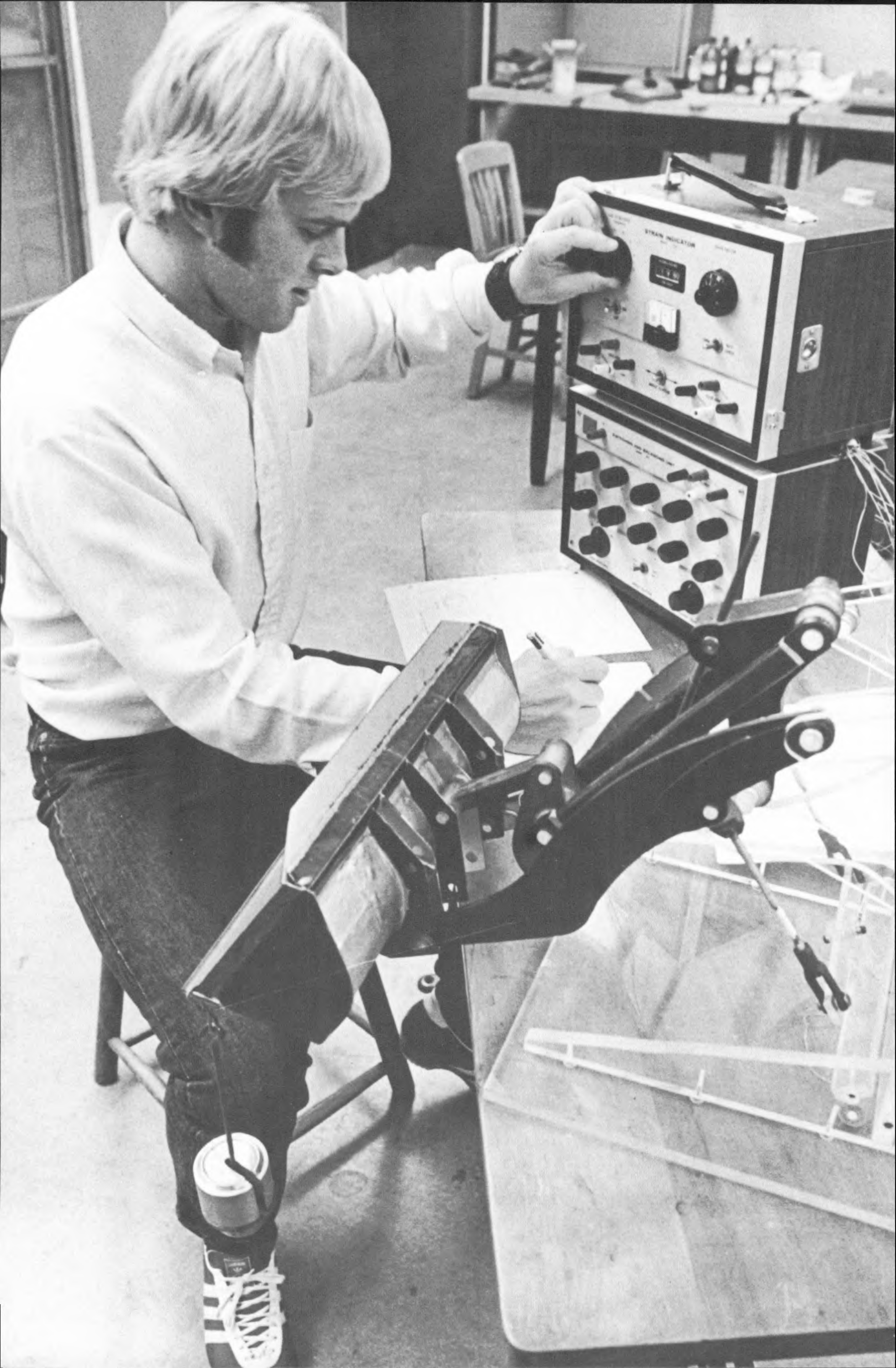
There are currently about fifty full-time graduate students enrolled in the Field of Mechanical Engineering.

Facilities

Special equipment available for graduate research in the Field of Mechanical Engineering includes a Mach-Zehnder interferometer; several schlieren systems; a solar furnace for high-temperature, controlled atmospheric heating; extensive hotwire anemometer equipment; devices for measuring secondary flows in rotation passages; a plasma arc facility; a combined steady-torque and reversed-bending fatigue testing machine; bearing-test machines for eccentric loading, for programmed load variations, and for shaft oscillations; special rigs for the dynamic loading of machine parts; automatic data recording instruments; and an extensive laboratory of machine tools and gages.

Also available to mechanical engineering graduate students are the University's large-scale computer facilities, both digital and analog. A terminal of the University computer is located in Upson Hall. A nuclear reactor facility is also available for student use.

By special arrangement, some thesis work may be carried out at the Brookhaven National Laboratory.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Areas of Research

Mechanical engineering has traditionally been divided into two main streams of technology. One stream is characterized by its concern with thermal phenomena; its subject areas are thermodynamics, fluid mechanics, and heat transfer, and the application of these disciplines to energy systems and thermal processes. The other stream is characterized primarily by a concern with mechanical phenomena; it involves the design, control, and production of machines, devices, and systems, and with the processing of materials. These two main streams of technology are fundamental to mechanical engineering at Cornell. Research activities in the graduate Field at the present time may be grouped, for convenience, into the categories listed below.

Fluid Mechanics

Work in basic fluid mechanics includes studies of wave motions and rotating flows, and numerical studies of turbulent and laminar flows. Current applications center on the fluid mechanical aspects of energy conversion and consequent environmental impact.

Studies of environmental fluid mechanics in progress include work on the thermal cycle of lakes, cooling-tower flows, lake and ocean mixing by wind driven convection cells, the meteorological impact of cities, pollutant dispersal in the atmosphere, and oil-pollution problems. These investigations combine theory, experiment, and computer simulations.

Vortex flows are being examined theoretically and experimentally and are of special interest for the design of efficient, nonpolluting gas turbine combustors. Associated experimental programs utilize a laser doppler anemometer, as well as extensive hot-wire anemometer equipment. Also in progress is theoretical research on nonlinear dispersive waves in fluid systems, and on fluid motions in planetary bodies.

Representative publications and theses are:

George, Y. H., and Moore, F. K. 1973. Nearly spherical constant-power detonation waves as driven by focused radiation. *Journal of Fluid Mechanics* 61(3):481.

Kopecky, R. M., and Torrance, K. E. 1973. Initiation and structure of axisymmetric eddies in a rotating stream. *International Journal of Computers and Fluids* (in press).

Leibovich, S., and Ulrich, D. 1972. A note on the growth of small-scale Langmuir circulations. *Journal of Geophysical Research* 77:1683.

Randall, J. D. 1972. Two Studies of Solitary Wave Propagation in Rotating Fluids. Ph.D. thesis. (Professor Leibovich.)

The stresses in a model are determined experimentally in order to verify computer-aided analysis and optimization procedures used for design of prototype mechanical systems.

Heat Transfer

Problems of current interest are concerned with heat rejection to the environment, natural convection flows and stability, the minimization of heat loss from buildings, two-phase flow, boiling heat transfer, and radiative transfer. Both experimental and theoretical programs are pursued. Heat transfer systems are also simulated and studied with the aid of computers.

Analytical and experimental interferometric studies are being made of laminar instability in steady and transient natural convection flows, and the development of turbulence in such flows. Studies of buoyant plumes in density-stratified atmospheres are also underway.

An environmental wind tunnel is available for studies of heat transfer to the atmosphere from urban areas. Complementary theoretical studies are being made of the impact of urban heat generation on the urban climate.

Also under study are problems of radiative transfer, especially as combined with gas dynamic phenomena and high-temperature gas flows.

Examples of recent publications and theses on these subjects are:

Audunson, T., and Gebhart, B. 1972. An experimental and analytical study of natural convection with appreciable thermal radiation effects. *Journal of Fluid Mechanics* 52:57.

Gutman, D. P. 1973. Impact of Heat Rejection on the Planetary Boundary Layer Above Cities. Ph.D. thesis. (Professor Torrance.)

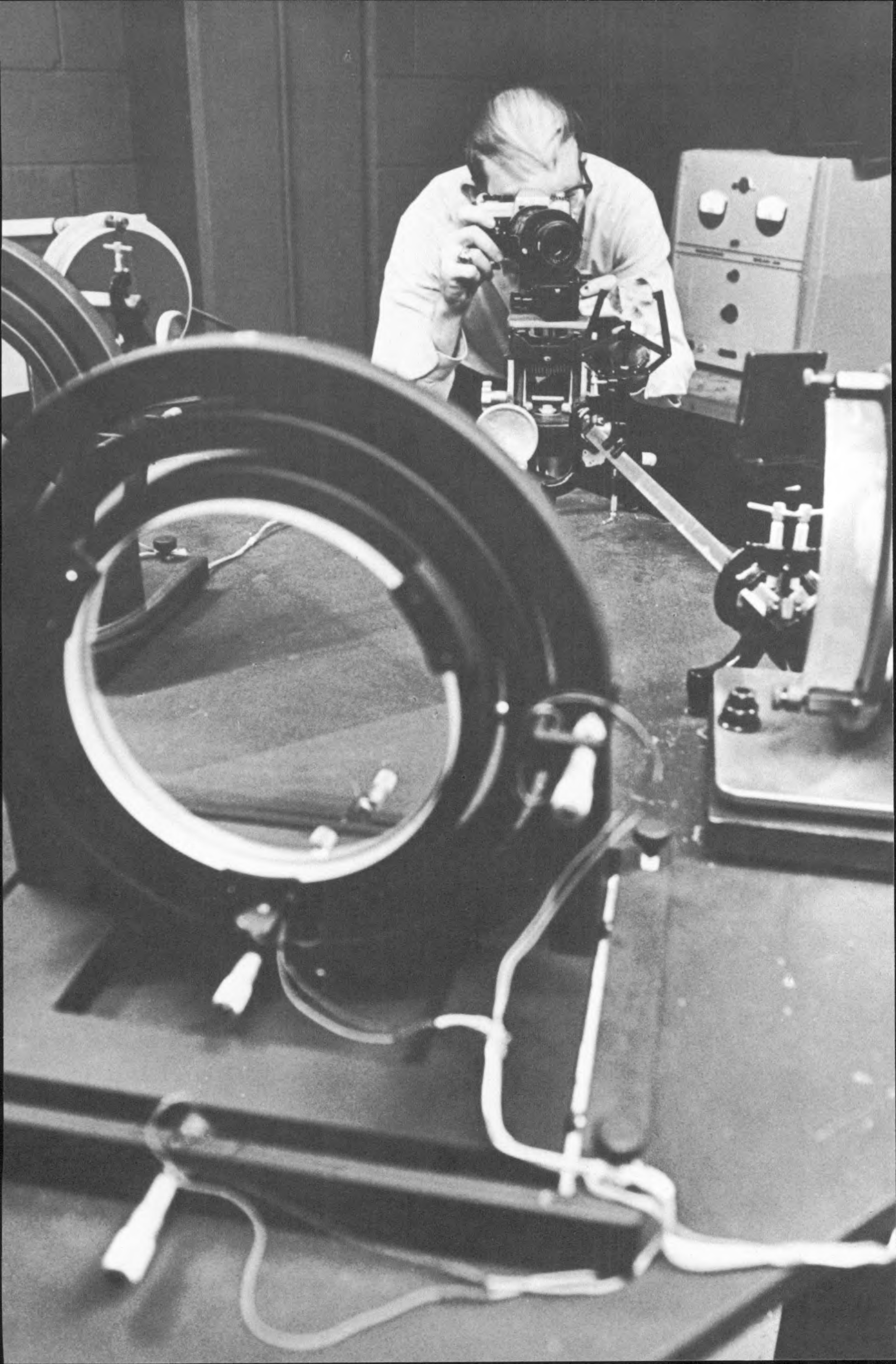
Torrance, K. E., and Turcotte, D. L. 1971. Global heat flow. In *Environmental and Geophysical Heat Transfer,* ASME HTD, Vol. 4, p. 90. New York: American Society of Mechanical Engineers.

Combustion

Combustion studies are underway in the areas of chemical kinetics, turbulent combustion, fire spread, and the generation of air pollutants. Additional subjects of faculty interest include flame spectroscopy and radiative transfer; diagnostic techniques, including mass spectrometric sampling; application of numerical techniques; and fire safety.

In the area of chemical kinetics, shock tube techniques are being used to study the elementary reactions involved in converting nitrogeneous fuel compounds to oxides of nitrogen. Kinetic mechanisms of fuel combustion and the formation of oxides of nitrogen are also under study. Turbulent combustion research has as its objective the development and testing of models to account quantitatively for the influence of turbulence on pollutant formation and combustion stability. Also under development are accurate models for the numerical calculation of fire spread over flammable liquids.

Combustion facilities include a gas chromatograph, mass spectrograph, a laser doppler velocimeter, and standard air-pollution monitoring equipment. Research opportunities exist in all of the programs described.



Recent papers on subjects in this area are:

Gouldin, F. C. 1973. Controlling emissions from gas turbines—the importance of chemical kinetics and turbulent mixing. *Combustion Science and Technology* 7:33.

McLean, W. J., and Sawyer, R. F. 1973. Molecular beam sampling from high pressure systems. *Acta Astronautica* (in press).

McLean, W. J.; Miller, J. A.; Resler, E. L.; and Bauer, S. H. 1973. Early Stages in the Mechanism of Methane Pyrolysis and Oxidation. Paper read at Eastern States Section of the Combustion Institute Fall Technical Meeting, 11–12 October 1973, in Montreal, Canada.

Torrance, K. E. 1971. Subsurface flows preceding flame spread over a liquid fuel. *Combustion Science and Technology* 3:133.

Power and Energy Systems

Generally speaking, this area encompasses studies of modern methods of energy utilization and their corresponding environmental effects. Current faculty interests reflect concern over problems which result from the rapidly increasing use of energy in a society faced with limited energy resources and requiring stringent environmental controls.

Among topics receiving current attention are combustion and transport processes in gas turbine combustors, which are being studied with a view toward the development of clean-burning turbine engines. Particular emphasis is placed on the relationship between fluid turbulence and nitric oxide production. Minimization of the production of nitric oxide in magnetohydrodynamic power systems is also being studied.

An experimental and analytical investigation of the feasibility of using alternate synthetic fuels, especially hydrogen, in reciprocating internal combustion engines is underway. Such fuels may be required as the supply of petroleum decreases. Also underway are studies of energy storage by power plants during low demand periods for subsequent use during peak load periods.

The generation of waste heat is of increasing concern as energy utilization increases. Studies are being carried out to determine the effects of heat rejection from sources widely distributed in area and from intense local sources. A study of the effect of thermal pollution on Cayuga Lake was completed recently, and research in cooling-tower technology is currently underway.

Also recently completed are studies of the monitoring and dispersion of atmospheric air pollutants.

Examples of recent publications and theses in this area are:

Photographic data from the Mach-Zehnder interferometer provides detailed pictures of patterns of energy and momentum transport in natural convection flows.

Gouldin, F. C., and Yue, B. 1973. *Kinetic study of two-stage combustion in MHD topping cycles.* Cornell Energy Project report no. 73–6. Ithaca, New York: Cornell University.

Hogue, R. A. 1973. The Optimum Distribution of Fossil Fuels to Northeast Power Plants. M.S. thesis. (Professor Gouldin.)

Hsia, L. L. 1973. Less Polluting Alternatives to Conventional Engines for Automotive Propulsion. M.S. thesis. (Professor Conta.)

Moore, F. K. 1974. On the minimum size of large dry cooling towers with combined mechanical and natural draft. *Journal of Heat Transfer* (ASME) 95C:383.

Shepherd, D. G. 1973. *Low Pollution on-site energy storage for peak power.* Mechanical and Aerospace Engineering report. Ithaca, New York: Cornell University.

Mechanical Systems and Design

This field of research is concerned with the broad area of the design, analysis, and manufacture of devices, machines, and systems. At Cornell these are broadly interpreted and encompass vehicle dynamics, biomechanics, and space applications as well as such traditional areas as lubrication, controls, and manufacturing processes. The common theme of the work is the application of analytical models, computer simulation, and experiment to important practical problems.

Recent work in the area of ***manufacturing processes*** has included studies of the mechanism of friction welding, thermal fracture of cutting tool materials, and computer-aided design of molds and processing of plastics.

Lubrication studies have been concerned with porous and elastic bearings, with both mechanical and biological applications. Other work in the area encompasses the study of the dynamics of large systems as affected by bearing characteristics.

Some recent work in the area of ***vehicle dynamics*** has been concerned with the detection and subsequent correction of tractor-semitrailer jackknifing. Conditions for optimal control of the articulated vehicle have been established, and a general method for the computer modeling of vehicles has been developed. Current work concerns tire characterization, truck aerodynamics, physical vehicle modeling, and motorcycle front wheel shimmy.

Biomechanics research is concerned with the analysis of biomechanical systems to promote better understanding of the structure and function of normal, impaired, and reconstructed physiological systems. Work is in progress on tissue and implant properties, with the intent of developing improved implants, tissue-implant systems, and surgical procedures. Current work involves the analysis and design of devices and surgical procedures in the orthopedic and rehabilitation area; these include the mechanical aspects of degenerative joint disease, reconstructive surgery of the knee, bone implant

systems, and upper extremity assistive device systems.

Work in controls and design reliability and optimization is also in progress.

Recent publications and theses in the area of mechanical systems and design include:

Booker, J. F., and Huebner, K. H. 1972. Application of finite-element methods to lubrication: An engineering approach. *Journal of Lubrication Technology* (ASME) 94, Series F (4):313.

Cusano, C., and Phelan, R. M. 1973. Experimental investigation of porous bronze bearings. *Journal of Lubrication Technology* (ASME) 95, Series F (2):173.

Eidelberg, B.E. 1974. Finite Element Analysis of Lubrication in Natural Joints. Ph.D. thesis. (Professor Booker.)

Markowsky, J. J. 1971. An Analytical Model for Predicting the Pressure and Flow Transients in a Gaseous H_2-O_2 100 lb. Thrust Reaction Control System Rocket Engine. Ph.D. thesis. (Professor McManus.)

Parker, R. A. 1973. The Analysis of the Forces and Displacements in the Digit of the Horse During Walk. M.S. thesis. (Professor Bartel.)

Rojeski, P. J. 1972. A Systems Analysis Approach to Landing Gear Design. Ph.D. thesis. (Professor Wehe.)

Schorr, A. W., and McManus, H. N., Jr. 1972. The modeling and design optimization of a space-oriented thermoelectric power supply. In *Proceedings of 7th intersociety energy conversion engineering conference*. Washington, D.C.: American Chemical Society.

Shah, H. M. 1973. A Mathematical Model of Heat Transfer During the Initial Stage of Inertia Welding. M.S. thesis. (Professor Wang.)

Susemihl, E. A., and Krauter, A. I. 1973. Jackknifing of Tractor-Semitrailer Trucks—Detection and Corrective Action. ASME paper no. 73-ICT-1, read at Intersociety Conference on Transportation, September 1973, in Denver, Colorado. To be published in the *Journal of Dynamic Systems, Measurement and Control*.

van Zanten, A. T. 1974. Optimal Control of the Tractor-Semitrailer Truck. Ph.D. thesis. (Professor Krauter.)

Wang, K. K., and Rasmussen, G. 1972. Optimization of inertia welding process by response surface methodology. *Journal of Engineering for Industry* (ASME) 94(4):999.

Upson Hall houses the administrative offices and some of the facilities of the Sibley School of Mechanical and Aerospace Engineering; the School of Industrial Engineering and Operations Research; the Department of Computer Science; and headquarters of the Laboratory of Plasma Studies.

Faculty Members and Their Research Interests

Donald L. Bartel, Ph.D. (Iowa): *design optimization and reliability; computer-aided design; biomechanical engineering*

John F. Booker, Ph.D. (Cornell): *lubrication; finite-element methods; computer-aided simulation and design*

Bart J. Conta, M.S. (Cornell): *thermodynamics; thermal power; energy conversion*

David Dropkin, Ph.D. (Cornell): *heat transfer; thermal power; refrigeration and air conditioning*

Benjamin Gebhart, Ph.D. (Cornell): *heat transfer; fluid mechanics; transport processes; environmental control*

Frederick C. Gouldin, Ph.D. (Princeton): *fluid dynamics; combustion; air pollution*

Allan I. Krauter, Ph.D. (Stanford): *dynamics of vehicles; automotive engineering; computer-aided design*

Sidney Leibovich, Ph.D. (Cornell): *fluid dynamics; wave propagation; rotating fluids*

William J. McLean, Ph.D. (Berkeley): *thermodynamics; air pollution; combustion*

Franklin K. Moore, Ph.D. (Cornell): *fluid dynamics; energy systems; thermal pollution*

Richard M. Phelan, M.M.E. (Cornell): *mechanical design; vibration; controls; lubrication*

Dennis G. Shepherd, B.S. Engr. (Michigan): *thermal power; fluid dynamics; turbomachinery*

Kenneth E. Torrance, Ph.D. (Minnesota): *computational fluid mechanics; combustion; geophysical heat transfer*

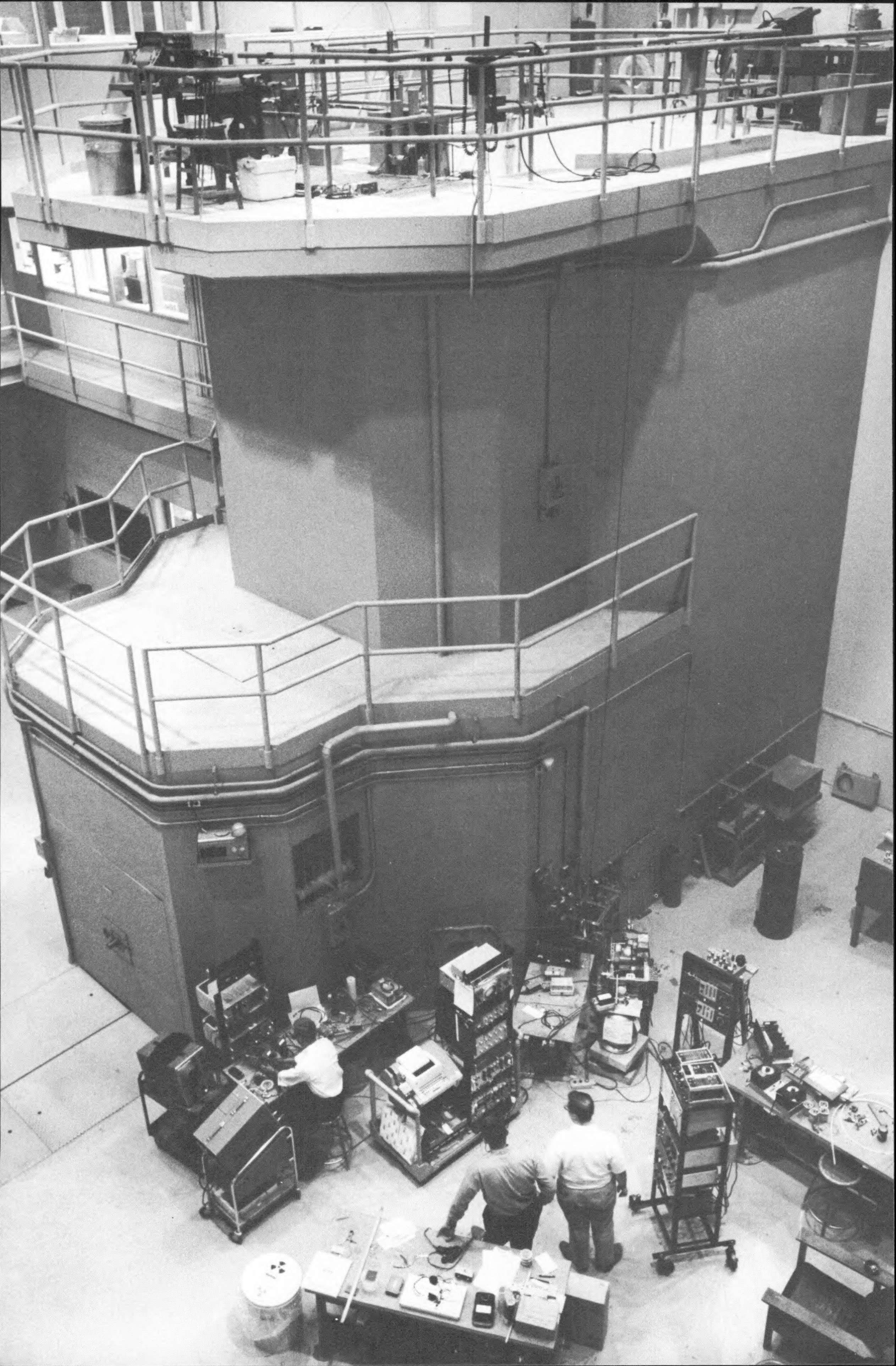
Kuo-King Wang, Ph.D. (Wisconsin): *manufacturing engineering; materials processing*

Robert L. Wehe, M.S. (Illinois): *lubrication; product design; design of components*

Further Information

Further information about the M.S. and Ph.D. degree programs may be obtained by writing to: Graduate Field Representative for Mechanical Engineering, Sibley School of Mechanical and Aerospace Engineering, Upson Hall, Cornell University, Ithaca, New York 14850.

Requests for further information about the M.Eng. (Mechanical) degree program should be addressed to: Program Representative, Master of Engineering (Mechanical), at the same address.



Nuclear Science and Engineering

Nuclear science and engineering is concerned with the understanding, development, and application of the science of nuclear reactors and radiations. The graduate programs at Cornell allow specialization in basic nuclear science, in applied nuclear engineering, or in a combination of the two. Minors may be chosen in a wide variety of other engineering or science fields. About twenty graduate students are concentrating in nuclear science and engineering at the present time.

Three graduate degree programs are offered. The Master of Engineering (Nuclear) is a professional degree; the Master of Science and Doctor of Philosophy degrees are intended for those who plan to pursue research or teaching careers. Degree program requirements and course offerings are described fully in other publications which may be obtained upon request; these are: the *Announcement of the College of Engineering*, the *Announcement of the Graduate School*, and the *Announcement of the Graduate School: Course Descriptions*. Only a brief summary is provided here.

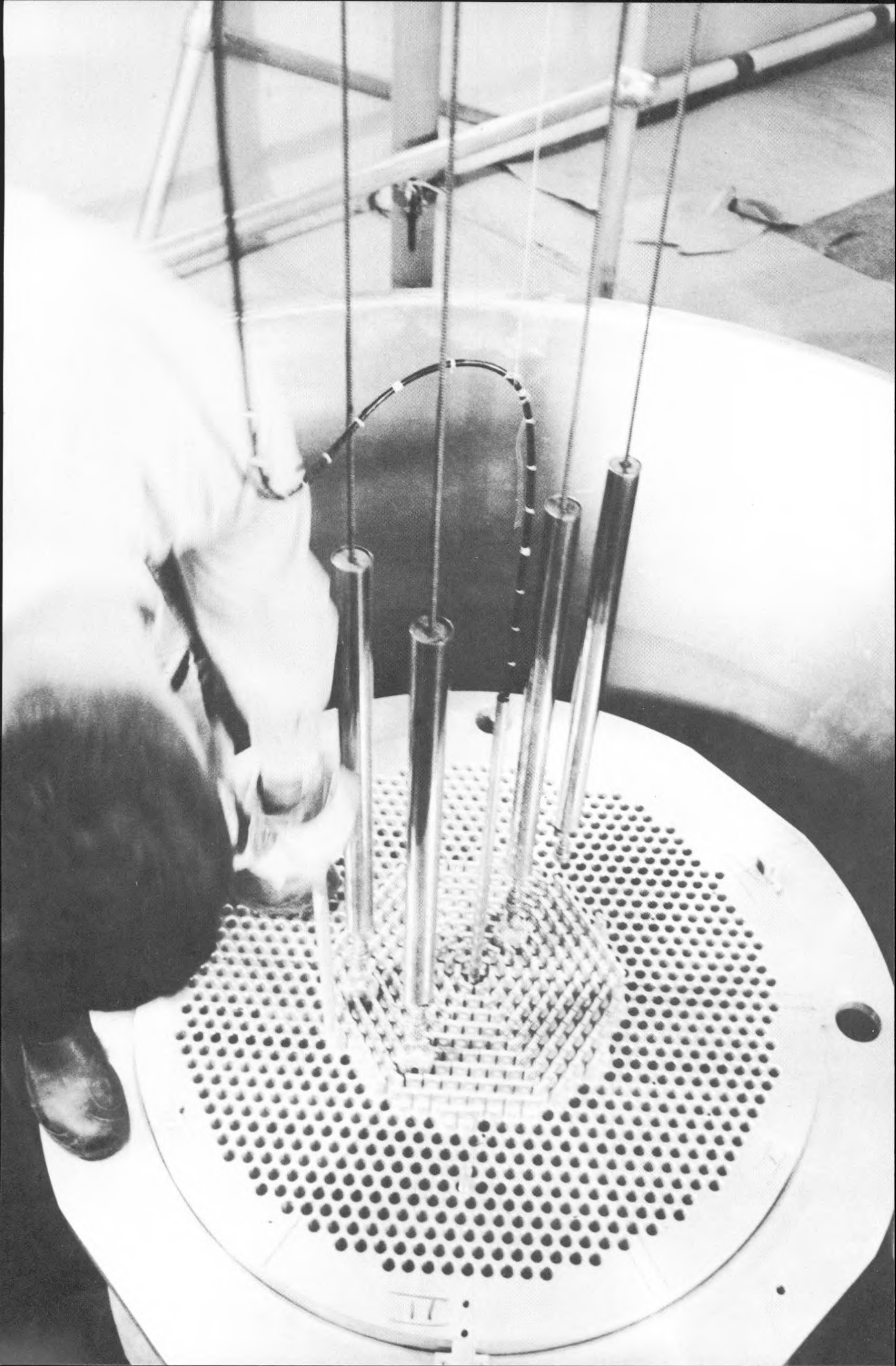
The Master of Engineering (Nuclear) degree program is intended primarily for individuals who want a terminal professional degree, but it may also serve as preparation for doctoral study in nuclear science and engineering. The two-term curricular program covers the basic principles of nuclear reactor systems, with a major emphasis on reactor safety and radiation protection and control. There is a growing need in the nuclear industry for engineers who have a thorough knowledge of these safety provisions and who are able to apply it to the design of reactor plants and auxiliary equipment and to the implementation of environmental monitoring systems. Required courses treat reactor safety and radiation protection and control in depth, and an elective course in radiation biology and an elective seminar in physical biology are available.

The background recommended for the program includes a baccalaureate degree or its equivalent in engineering or applied science; physics, including atomic and nuclear physics; mathematics, including advanced calculus; and thermodynamics. Students should have fulfilled these requirements before beginning the program. In some cases, deficiencies in preparatory work may be made up by informal study during the preceding summer.

Required for the M.Eng. (Nuclear) degree are thirty credit hours of instruction, including an engineering design project, but no thesis. The required courses are: Nuclear Reactor Theory, Nuclear Reactor Engineering, Nuclear Measurements Laboratory, and Low-Energy Nuclear Physics. In addition to these required courses, two elective courses in engineering and one in mathematics or physics are required. The engineering electives must be in a subject area that is relevant to nuclear engineering. Examples of electives that have been chosen are the following courses offered by various schools and departments of the University. Applied and Engineering Physics: Introduction to Plasma Physics, Advanced Plasma Physics, Thermonuclear Fusion Reactors. Mechanical and Aerospace Engineering: Energy Conversion, Heat Transfer, Fluid Mechanics, Large Scale Heat Rejection. Electrical Engineering: Feedback Control Systems, Electric Energy Systems. Physical Biology: Biological Effects of Radiation, Elements of Physical Biology. Computer Science: Computer Organization and Programming, Numerical Analysis. Mathematics: Mathematical Methods of Physics, Applicable Mathematics. Physics: Quantum Mechanics, Theoretical Physics, Design of Electronic Circuitry.

The M.S. and Ph.D. programs are oriented toward research and require completion of a thesis as well as course work. A candidate for one of these degrees chooses either nuclear science or nuclear engineering as his major subject, but because each student plans an individual program in consultation with the faculty members on his Special Committee, there are no detailed degree requirements. This approach, long a tradition of graduate study at Cornell, is well suited to interdisciplinary fields such as nuclear science and engineering. Minor subjects may be in any related engineering or science field; some possibilities are implied by the list of elective courses in the previous paragraph. Independent research leading to the writing of a

The TRIGA reactor, a source of neutrons and gamma rays, is used in graduate research projects in nuclear science and engineering.



thesis, and formal and informal interactions with staff members and other students, are vital parts of the program.

The appropriate preparation for graduate work in these programs is an undergraduate education in science, applied science, or engineering, with special emphasis on mathematics and modern physics.

Facilities

The Ward Laboratory of Nuclear Engineering is the major facility at Cornell for graduate research and teaching. It is the center for study of reactor physics and engineering, low energy nuclear structure physics, and nuclear and radiation chemistry. The following primary facilities are housed in the Laboratory.

A TRIGA reactor, which has 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 research in nuclear physics. In addition to standard pneumatic and mechanical transfer systems, the reactor has a 40-millisecond rapid transfer mechanism that allows study and use of radionuclides having a relatively short half-life.

A critical facility, or "zero-power" reactor, of versatile design. This facility, unique to Cornell University, is used for basic studies in reactor physics and dynamics. Auxiliary equipment includes a pulsed 14-MeV neutron generator used for studies of reactor transients.

A shielded gamma cell with a 4,000-curie ^{60}Co gamma-ray source. This is used for studies of radiation chemistry and radiation damage. Experimental versatility is facilitated by a viewing window and remote manipulators.

A 3 MeV Dynamitron, or positive-ion accelerator, with up to 2.5-mA beam current. This is used for studies of atomic and nuclear structure and high intensity radiation damage. A lithium target capable of power dissipation approaching 10,000 watts per cubic centimeter has been developed for use in controlled energy neutron production.

In addition to these and other special items of equipment in the Ward Laboratory, facilities of other departments are available. The general resources of the University include a computing system with a central machine, several satellite stations, and a number of teletypewriter terminals.

Unique to Cornell University is a critical facility or "zero power reactor" used for research in reactor physics and dynamics.

Areas of Research

Beacuse of the wide range of available facilities, thesis research may be undertaken in any of several major areas. Research subjects in nuclear science include low-energy nuclear structure physics; the interaction of atomic and nuclear processes; X-rays produced in ion-atom collisions; nuclear geochemistry and cosmochemistry; and activation analysis. Subject areas in nuclear engineering include nuclear environmental engineering; reactor plant dynamics and safety; experimental and analytical reactor physics; neutron transport theory; radiation effects on materials, including fast neutron damage; and radiation protection and control. Some of the current projects are described below.

Nuclear Environmental Engineering

Research in this area is conducted under the auspices of the Cornell Energy Project, an interdisciplinary research effort, begun in 1970, to investigate national energy needs and environmental quality. Part of this research is in the development of optimal strategies for the installation and operation of facilities for the generation of electricity: base-loaded nuclear plants, intermediate-and base-loaded fossil-fuel plants, and peak-loaded pumped storage and gas-turbine plants. Taken into account as part of the total cost associated with any strategy are environmental and health costs resulting from the mining and burning of nuclear and fossil fuels and from the reprocessing and disposal of radioactive wastes.

Examples of reports issued by the Project are:

Braun, C., and Cady, K. B. 1973. *An electric power system expansion model.* Cornell Energy Project Report, 1973.

Franco, J. A., and Cady, K. B. 1972. *Radioactive waste management at nuclear fuel reprocessing plants.* Cornell Energy Project Report, 1972.

Nuclear Safety Engineering

Safety research in light-water reactors and fast-breeder reactors is important in the expansion and development of nuclear energy. A recent Cornell research project resulted in the development of probabilistic models for determining optimum testing frequencies, testing methods, and replacement schedules for the maintenance and operation of nuclear plant safety systems. A second example of the results of research is the development of fast-reactor plant models and computer codes for the control and analysis of nuclear plant transients and accidents.

Representative of recent research in this area is the following doctoral dissertation:

Schleicher, R. W., Jr. 1972. Stochastic Decision Making Applied to Nuclear Reactor Safety. Ph.D. thesis. (Professor Cady.)

Nuclear Materials Research

The economic and orderly development of fast-reactor and fusion-reactor technology requires an understanding of the phenomena of radiation-induced swelling and creep. An example of Cornell research in this area is the development of a theory of void coalescence and growth which accounts for the observed swelling and decrease in void density of stainless steels at low doses and predicts behavior at high doses.

One of the publications based on this research is:

Mansur, L. K.; Okamoto, P. R.; Taylor, A.; and Li, C.-Y. 1973. *Void coalescence and growth in metals under irradiation.* Report no. 2020, Materials Science Center, Cornell University.

Fission Reactor Physics

Basic research in the kinetics of the neutron chain reaction is carried out in conjunction with the reactor plant dynamics work discussed above. The main experimental facility for basic reactor physics is the Cornell critical facility. One example of research is the measurement of neutron importance functions, and another is the measurement and interpretation of neutron density waves propagating through multiplying media. The critical facility is of very flexible design, and a large variety of cores of different shapes, sizes, and water-to-fuel ratios can be investigated. It is a unique educational tool for the operational understanding of nuclear reactor cores.

An example of journal publications in this field is:

Greenspan, E., and Cady, K. B. 1970. The measurement of neutron importance functions. *Journal of Nuclear Energy* 24:529.

Low-Energy Nuclear Physics

Among projects now under way in this area is an experimental study of isomeric (metastable) excited states in nuclei. The energies, spins, parities, lifetimes, and other parameters of these levels can be compared with predictions from theoretical models and thus provide checks on the validity of these models. Several high-spin isomers have been discovered at Cornell with use of the TRIGA reactor and the fast transfer system.

Isomeric states frequently decay by internal conversion, producing vacancies in the inner electron shells of the atom, and this results in X-ray emission. A new method for determining properties of isomeric levels solely by observation of these X rays has been developed in the course of research on ^{182}Ta. The method is applicable to other nuclides.

The discovery of spontaneously fissioning isomers and recent theoretical research at various laboratories have led to the hypothesis of a new type of isomerism called "shape isomerism." The phenomenon, which is widespread among elements of atomic number 92 and higher, is due to a double-hump in the fission barrier. Nuclei in the isomeric state are stretched into a cigar-like shape, with the polar axis almost twice the equatorial diameter. Experiments designed to measure the degree of "stretch" and other properties such as the expected decay of the isomer by modes other than fission are under way with use of neutrons from the TRIGA reactor. Experiments using higher energy neutrons from the Dynamitron are also planned.

A new type of detector—the inner-shell vacancy (ISV) detector—was recently conceived and developed at Cornell in order to make feasible a key series of shape-isomer experiments using reactor neutron beams.

Examples of recent publications in this area are:

Clark, D. D. 1971. Shape isomerism and the double-humped fission barrier. *Physics Today* 24(12):23.

Clark, D. D.; Kostroun, V. O.; Siems, N. E.; and Kane, W. R. 1973. Gamma-ISV coincidence studies of Ag-110. *Bulletin of the American Physical Society* 18:1424.

Atomic Processes

In recent years there has been a growing interest in inelastic collisions between atomic systems and energetic ions or heavy charged particles such as protons and alphas. This interest has been motivated by both theoretical and practical considerations such as the desire to extend knowledge of atomic-ionic interactions, and questions about atomic structure and dynamical properties of decay of many-electron atoms or ions from states of high excitation.

From a practical standpoint, the inelastic energy loss, the types of radiation emitted, the manner of excitation and ionization by fast charged particles, and the total inelastic cross section all have broad applicability in various areas of physics and other sciences. Depending on the atomic species and incident energies involved, applications exist in astrophysics, plasma physics, the study of radiation damage of materials, radiation biology, radiation therapy, and trace-element analysis.

The Cornell Dynamitron is used in conjunction with a two-crystal vacuum spectrometer for detailed investigation of the formation and radiative deexcitation of both singly and multiply ionized atoms formed as a result of collisions with energetic ions or heavy charged particles. Quantities investigated include radiative and nonradiative transition probabilities of multiply ionized atoms produced in energetic (MeV) ion-atom collisions and specific initial-state ionization cross sections. The manner in which these parameters depend on the initial and final states of the atom are also studied.

Examples of recent publications and theses based on this research are:

Kostroun, V. O.; Chen, M. H.; and Crasemann, B. 1971. Atomic radiationless transition probabilities to the ls state and theoretical K-shell fluorescence yields. *Physical Review A* 3:533.

Glancy, J. E. 1972. An Experimental Study of the Low Energy X-ray Induced Luminescence of Argon Gas in the Region 1800–6000 Angstroms. Ph.D. thesis. (Professor Kostroun.)

Nuclear Geochemistry and Activation Analysis

Research in multielement trace analysis of geological, metallurgical, and biological materials by neutron activation techniques is carried out with the TRIGA reactor. Other analytical techniques such as spark source mass spectroscopy are also employed.

An example of recent papers that have resulted from this research is:

Morrison, G. H.; Gerard, J. T.; Potter, N. M.; Gangadharam, E. V.; Rothenberg, A. M.; and Burdo, R. A. 1971. Elemental abundances of lunar soil and rocks from Apollo 12. In *Proceedings of the 2nd lunar science conference*, p. 1169. Boston: M.I.T. Press.

Faculty Members and Their Research Interests

Faculty members in a number of University departments are engaged in research programs that have a major emphasis on nuclear science and engineering. The following listing of faculty members in the graduate Field of Nuclear Science and Engineering, their departmental affiliations (in parentheses), and their areas of interest related to this Field indicates the scope of research that can be undertaken:

K. Bingham Cady (Applied Physics): *nuclear engineering; nuclear environmental engineering; nuclear reactor physics*

Alison P. Casarett (Physical Biology): *radiation biology; physical biology*

David Dropkin (Thermal Engineering): *heat transfer; energy conversion*

David D. Clark (Applied Physics): *nuclear structure physics; nuclear instrumentation*

Hans H. Fleischmann (Applied Physics): *thermonuclear power; plasma physics*

Charles D. Gates (Environmental and Water Resources Engineering): *nuclear environmental engineering*

Bryan L. Isacks (Geological Sciences): *seismological aspects of nuclear power plant siting*

Vaclav O. Kostroun (Applied Physics): *nuclear structure physics; interaction of atomic and nuclear processes; atomic physics*

Che-Yu Li (Materials Science and Engineering): *nuclear materials; fast-neutron damage*

Simpson Linke (Electrical Engineering): *energy conversion and transmission*

Raphael M. Littauer (Physics and Nuclear Studies): *nuclear pulse electronics*

Franklin K. Moore (Mechanical and Aerospace Engineering): *thermal engineering; energy conversion*

George H. Morrison (Chemistry): *nuclear geochemistry and cosmochemistry; activation analysis*

Mark Nelkin (Applied Physics): *neutron scattering and transport*

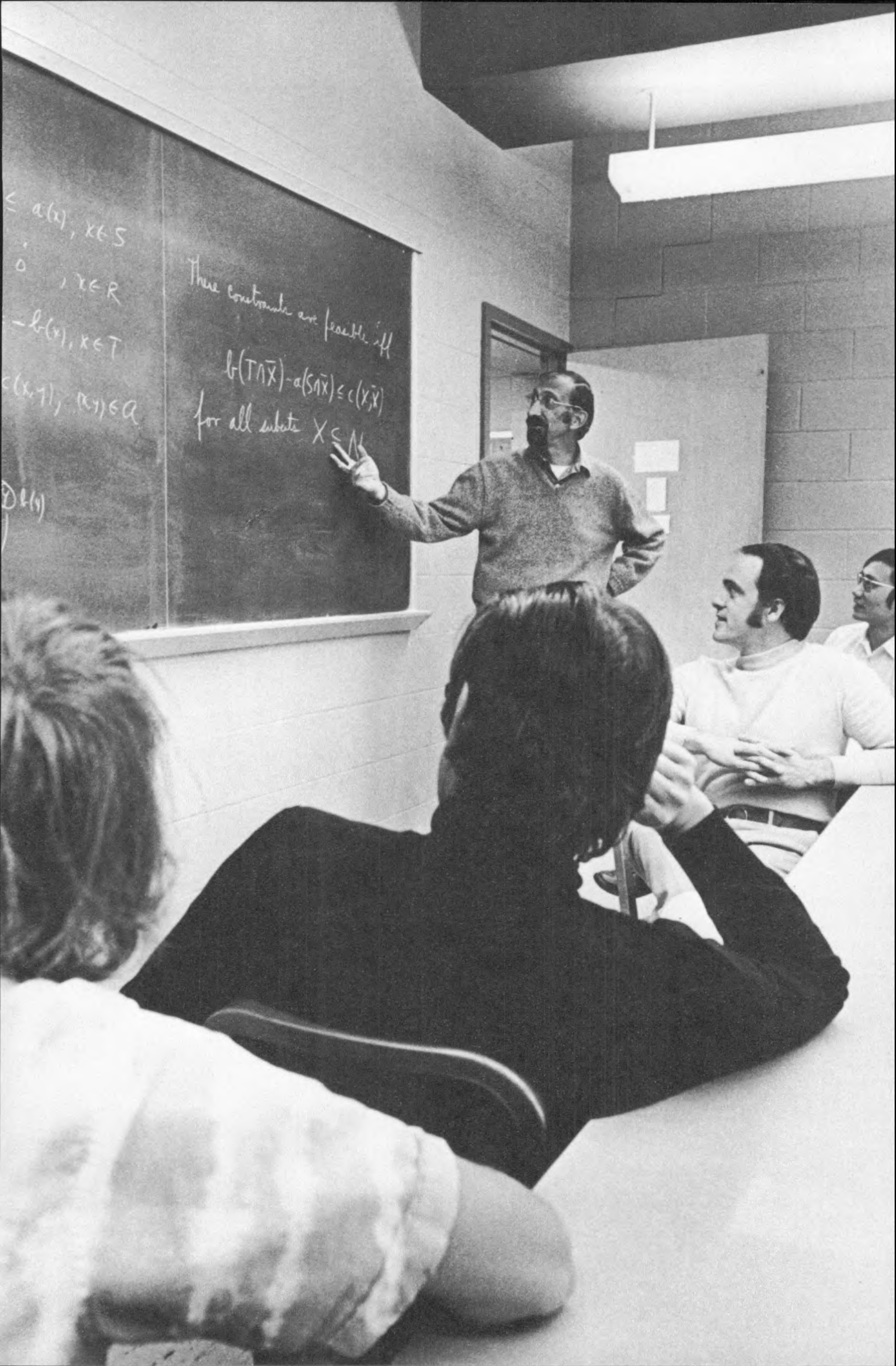
James S. Thorp (Electrical Engineering): *systems engineering; controls*

Robert L. Von Berg (Chemical Engineering): *radiation chemistry*

Further Information

Further information about the M.S. and Ph.D. degree programs may be obtained by writing to: Graduate Field Representative, Nuclear Science and Engineering, Ward Laboratory of Nuclear Engineering, Cornell University, Ithaca, New York 14850.

Requests for further information about the M.Eng. (Nuclear) degree program should be addressed to: Master of Engineering (Nuclear) Representative at the above address.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Operations Research

The graduate Field of Operations Research offers doctoral programs in four major subjects: operations research, applied probability and statistics, systems analysis and design, and industrial engineering. Master of Science programs are offered in all these subjects, and in information processing as well.

Also offered, under the auspices of the School of Industrial Engineering and Operations Research, is a one-year program leading to the professional degree of Master of Engineering (Industrial).

More than sixty-five full-time graduate students, including thirty from foreign countries, are currently registered in these programs. Approximately one-third of the students hold undergraduate degrees in mathematics; the others majored in engineering or other sciences.

Major Subject Areas

A general description of the five subject areas in the Field of Operations Research is given below.

Operations Research

The problem areas and techniques of operations research are approached from a highly analytical viewpoint. Theories and techniques from mathematical programming (linear, nonlinear, dynamic, and probabilistic), combinatorics, theory of games, stochastic processes (queuing and inventory), scheduling, and simulation are developed and used extensively. Consideration is given to the construction of appropriate mathematical models to represent various real-life operational systems, and to the development of techniques for analyzing the performance of these models.

The operations research student pursues a course of study and research that emphasizes the use of the mathematical, probabilistic, statistical, and computational sciences in the development of the techniques of operations research. His ultimate goal may range from making a fundamental contribution to the techniques of operations research to applying these techniques to problems in diverse professional fields.

Operations research students participate in a graduate class in network flows and extremal combinatorial problems.

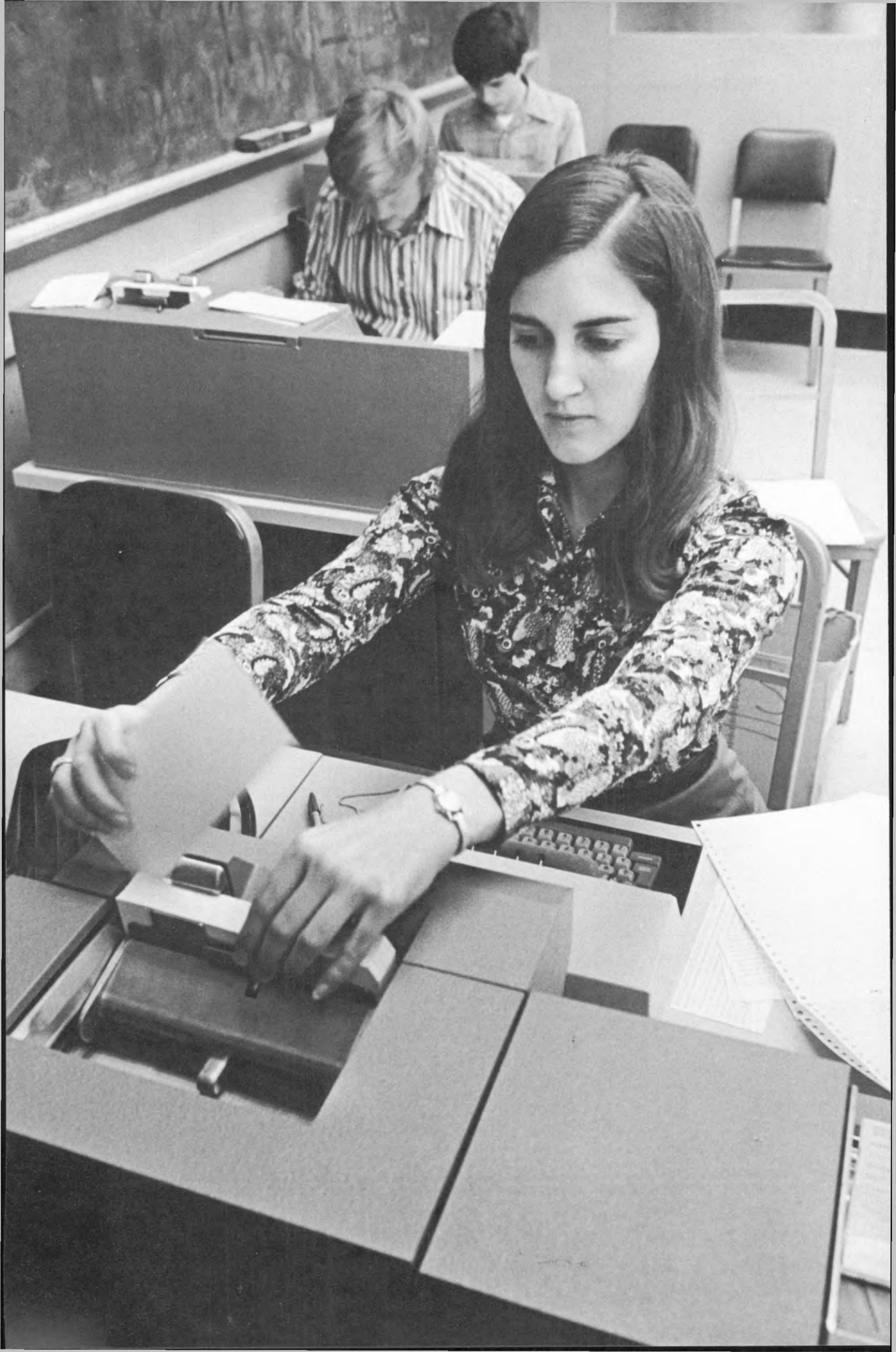
Applied Probability and Statistics

This subject of study and research is designed for students having primary interest in the techniques and associated underlying theory of probability and statistics, particularly as they are applied to problems arising in science and engineering. 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).

Those who elect to work in this area are expected to acquire considerable knowledge of the theory of probability and statistics. All students who major in applied probability and statistics are required to have the equivalent of a minor in mathematics.

Systems Analysis and Design

Although the solution of a systems problem 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 selection of the one which can best be integrated with other elements of the system. 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 activity may involve the development of new methodology or the synthesizing of new combinations from what is already known. The goal is to improve the understanding of systems or to develop new decision criteria for systems.



Industrial Engineering

Studies of the analysis and design of the complex operational systems that occur in industry, particularly in manufacturing, are included in this subject. Plant design, cost analysis and control, and production planning are some of the major topics. A student is expected to have considerable facility in the modern analytical techniques associated with rational decision making and 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 apply 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

Information processing deals with the analysis and design of systems which record, transmit, store, and process information. Emphasis is on the application and integration of equipment rather than on 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 data structure, operating system organization, and computing language structure.

The principal campus computing facility is an IBM 360/65, with on-line operation from many campus locations. A satellite computer, 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. The 360/65 system is to be replaced by a larger-capacity 370/168 system in 1974.

Minor Subject Areas

In addition to choosing a major subject, candidates for the M.S. and Ph.D. degrees choose minors, which may be selected from the five areas described, or from those offered by other fields of the Graduate School. Appropriate minors that have been chosen most frequently in recent years, and the departments or schools which offer such courses of study are: applied mathematics (Applied Mathematics), computer science (Computer Science), econometrics and economic statistics (Economics), public systems planning and analysis (Civil and Environmental Engineering), managerial economics (Business and Public Administration), mathematics (Mathematics), and planning theory and systems analysis (City and Regional Planning).

Many graduate research problems in operations research involve the use of computing facilities.

Areas of Research

A research project is an important part of the program for all M.S. and Ph.D. degree candidates. Because the research is begun at an early stage, candidates who plan to seek the doctorate are encouraged to apply for a Ph.D. program at the outset.

The range of research opportunities is suggested by the projects currently being directed by members of the faculty. Topics of these research projects are:

Applied Stochastic Processes (sponsored by the National Science Foundation)

Asymptotically Optimal Statistical Procedures in Nonstandard Cases (sponsored by the National Science Foundation)

The Cooperative Theory of Behavior and Its Applications (sponsored by the Office of Naval Research)

Markov Sequential Decision Processes (sponsored by the National Science Foundation)

Mathematical Models for Large-Scale Combinatorial Problems in Resource Allocation (sponsored by the Office of Naval Research)

Multiple Decision Selection and Ranking Procedures (sponsored by the Army Research Office, Durham)

Optimal Set Covering (sponsored by the National Science Foundation)

PL/C Compiler Development (sponsored by the IBM Corporation and Siemens Corporation)

Privacy and Security in Information Systems (sponsored by the National Science Foundation)

Stability in Multi-person Games (sponsored by the National Science Foundation)

Statistical Engineering (sponsored by the Office of Naval Research)

Stochastic Congestion Systems (sponsored by the National Science Foundation)

Some books and recent research papers by faculty members are the following:

Bechhofer, R. E.; Kiefer, J.; and Sobel, M. 1968. *Sequential identification and ranking procedures.* Chicago: University of Chicago Press.

Billera, L. J. 1972. Global stability in n-person games. *Transactions of the American Mathematical Society* 172:45.

Conway, R. W.; Maxwell, W. L.; and Miller, L. W. 1967. *Theory of scheduling.* Reading, Massachusetts: Addison-Wesley.

Dearing, P. M. (with Francis, R. L.) 1973. A network flow solution to a multi-facility minimax location problem. To be published in *Transportation Science.*

Eisner, M. J. (with Kaplan, R. S., and Soden, J. V.) 1971. Admissible decision rules for the E-model of chance-constrained programming. *Management Science* 17(5):337.

Fulkerson, D. R., and Ford, L. R., Jr. 1962. *Flows in networks.* Princeton: Princeton University Press.

Jaquette, S. C. 1973. Markov decision processes with a new optimality criterion: Discrete time. *Annals of Statistics* 1:496.

Lucas, W. F. 1971. Some recent developments in n-person game theory. *SIAM Review* 13(4):491.

Maxwell, W. L., and Severance, D. G. 1973. Comparison of alternatives for the representation of data items in an information system. *Proceedings of the Wharton Conference on Research on Computers in Organizations,* University of *Pennsylvania.*

Nemhauser, G. L., and Garfinkel, R. 1972. *Interger programming.* New York: Wiley.

Prabhu, N. U. 1965. *Queues and inventories.* New York: Wiley.

Saunders, B. W. 1971. Facilities design: A problem of systems analysis. *International Journal of Production Research* 9(1):3.

Severence, D. G. 1973. Search mechanisms: A survey and generalized model. To be published in *Computing Surveys.*

Spitzer, F. L. 1964. *Principles of random walk.* Princeton: Van Nostrand.

Stidham, S., Jr., and Prabhu, N. U. 1973. Optimal control of queuing systems. To be published in *Proceedings of Conference on Mathematical Methods in Queuing Theory,* Western Michigan University, Kalamazoo.

Taylor, H. M. (with Costello, W. G.) 1971. Deterministic population growth models. *American Mathematical Monthly* 78:841

Todd, M. J. (with Duguay, C. and Wagner, H. M.) 1973. Linear programming with relative bounded variables. *Management Science* 19(7):751.

Weiss, L., and Wolfowitz, J. 1974. *Maximum probability estimators.* New York: Springer-Verlag.

An idea of the specific research conducted by graduate students, and also of the kind of jobs they assume after receiving their degrees, may be obtained from the following list of candidates who were awarded Ph.D. degrees within the past two years. Their present positions, their thesis topics, and their supervising professors are also given.

Babad, J., Assistant Professor, Graduate School of Business, University of Chicago. Price Scheduling in a Time-Sharing Queuing System. (Professor Maxwell.)

Bixby, R., Assistant Professor, Department of Mathematics, University of Kentucky. Composition and Decomposition of Matroids and Related Topics. (Professor Billera.)

Cherniavsky, E., Research Intern, Brookhaven National Laboratory. Some Contributions to Failure Models: The Shock and Continuous Danger Processes. (Professor Taylor.)

Collins, D., Cost Analysis Officer, Aeronautical Systems Division, Wright-Patterson Air Force Base. A Model for Cash Position Management. (Professor Bernell K. Stone of the Business and Public Administration faculty.)

Costello, W., Visiting Assistant Professor, Statistical Laboratory, State University of New York, Buffalo. Mathematical Models of the Sterile Male Technique of Pest Control. (Professor Taylor.)

Frischtak, R., Assistant Professor, Department of Statistics, University of California, Berkeley. Statistical Multiple-Decision Procedures for Some Multivariate Selection Problems. (Professor Bechhofer.)

Jacoby, I., Assistant Professor, Department of Statistics, Tel Aviv University, Israel. Asymptotically Most Efficient Stochastic Approximation. (Professor Weiss.)

Kennedy, S., Assistant Professor, Department of Industrial and Systems Engineering, San Jose State College, California. The Use of Access Frequencies in Data Base Organization. (Professor Morgan.)

Trotter, L., Assistant Professor, Department of Administrative Sciences, Yale University. Solution Characteristics and Algorithms for the Vertex Packing Problem. (Professor Nemhauser.)

Weinberger, D., Member, Technical Staff, Operations Research Methodology Group, Bell Telephone Laboratories. Investigations in the Theory of Blocking Pairs of Polyhedra. (Professor Fulkerson.)

Faculty Members and Their Research Interests

Robert E. Bechhofer, Ph.D. (Columbia): *statistical selection procedures*

Louis J. Billera, Ph.D. (City University of New York): *game theory; combinatorics*

Richard W. Conway, Ph.D. (Cornell): *information processing systems*

Perino M. Dearing, Ph.D. (University of Florida): *facilities location and design*

Mark J. Eisner, Ph.D. (Cornell): *mathematical programming*

D. Ray Fulkerson, Ph.D. (Wisconsin): *network flow theory; combinatorics*

Stratton C. Jaquette, Ph.D. (Stanford): *inventory and Markov decision processes*

Jack C. Kiefer, Ph.D. (Columbia): *statistical decision theory*

William F. Lucas, Ph.D. (Michigan): *game theory; combinatorics*

Walter R. Lynn, Ph.D. (Northwestern): *environmental systems*

William L. Maxwell, Ph.D. (Cornell): *information processing; simulation*

George L. Nemhauser, Ph.D. (Northwestern): *mathematical programming*

Narahari U. Prabhu, M.Sc. (Manchester, England): *stochastic processes; queuing and control*

Sidney Saltzman, Ph.D. (Cornell): *information processing systems*

Thomas J. Santer, Ph.D. (Purdue): *statistical selection procedures*

Byron W. Saunders, M.S. (Stevens Institute of Technology): *industrial systems; economic analysis*

Andrew Schultz, Jr., Ph.D. (Cornell): *systems analysis*

Dennis G. Severance, Ph.D. (Michigan): *information processing systems*

Frank L. Spitzer, Ph.D. (Michigan): *probability theory*

Shaler Stidham, Jr., Ph.D. (Stanford): *queuing theory; transportation systems*

Howard M. Taylor 3d, Ph.D. (Stanford): *applied probability*

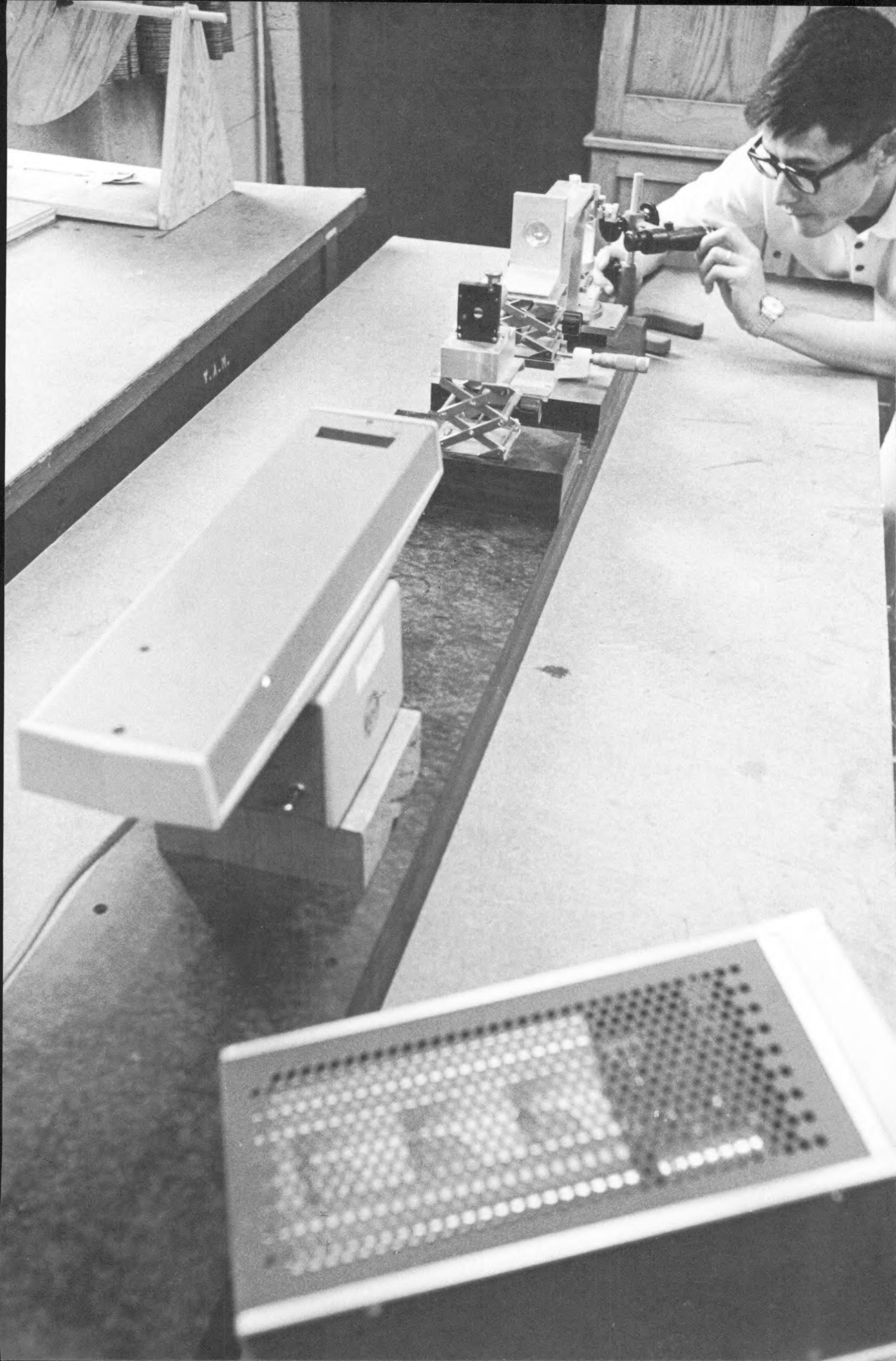
Michael J. Todd, Ph.D. (Yale): *mathematical programming*

Lionel I. Weiss, Ph.D. (Columbia): *statistical decision theory*

Further Information

Inquiries about graduate programs in the Field of Operations Research may be addressed to: Graduate Field Representative, Operations Research, Upson Hall, Cornell University, Ithaca, New York 14850.

Inquiries about the professional degree program may be addressed to: Master of Engineering (Industrial) Representative, at the same address.



Theoretical and Applied Mechanics

Mechanics is the study, by mathematical analysis as well as by experimental observation, of the motion and deformation of solids and fluids. Although its historical roots are deep, it is a particularly modern subject because it is basic to so many areas of modern technology. Graduates of the Cornell programs in theoretical and applied mechanics have a solid background in fundamentals, are able to carry out analytical work of high quality, and are aware of the interdisciplinary nature of many modern engineering problems. These strengths have proved to be particularly valuable in recent years in areas such as structural analysis, aerodynamics, bioengineering, and satellite or vehicular dynamics and control.

Theoretical and Applied Mechanics is the only purely graduate department in the College of Engineering. It provides a program which gives a student a broad training in the discipline of mechanics as well as in the mathematical methods and experimental techniques that permit real problems to be solved. The student is then given the opportunity to do basic and meaningful original research, which provides him with the preparation to continue work in any of several different technical areas. Throughout a student's stay, emphasis is placed on his use of fundamental knowledge to develop new avenues of attack on contemporary problems. Thus, while the basic analytic and experimental character of the discipline is stressed, research work naturally is directed to specific and sometimes applied goals, for only by delving deeply into an actual problem can the research process be understood.

The principal areas of teaching and research of the Field are solid mechanics, biomechanics, mathematical methods, space dynamics, fluid mechanics and mechanics of materials. There is significant overlap with other graduate fields, however, since the nature of the study of mechanics lends itself to adoption by a variety of other engineering and non-engineering fields whenever quantitative models for specific processes are sought. For example, it is expected that research in applied mathematics, biomechanics, geological and astronomical applications, and the study of composite materials will continue to be prominent among the Field's research topics.

The approximately twenty-five graduate students in the Field of Theoretical and Applied Mechanics come from a variety of academic and national backgrounds. Most are studying for the Ph.D., although some are enrolled in the Master of Science degree program. In addition, a program leading to the professionally oriented degree of Master of Engineering (Engineering Mechanics) has been instituted recently.

Most graduate students in the Field are supported by Cornell University fellowships or by teaching and research assistantships. Teaching assistants provide significant help, primarily with the undergraduate courses in mechanics and applied mathematics that are offered by the Department of Theoretical and Applied Mechanics. Research assistants receive support through grants and contracts with industrial or government agencies.

The Field seeks to attract prospective students who show a profound interest in basic studies in mechanics and who have a strong aptitude for analysis or fundamental experimental work. Typically, a student with analytical interests pursues theoretical studies, using published experimental results to delimit the study. A student more interested in physical phenomena and their measurement may concentrate his research in some aspect of experimental science, such as a study of the various properties of materials. Of course, students are often encouraged to work in an area somewhere between the purely abstract and the purely experimental, for it is felt that usually efforts of this type result in the most relevant contributions to science and technology.

In addition to taking courses given by the Department of Theoretical and Applied Mechanics, students may select from the wide variety of courses offered by other University departments. There are no formal course requirements at Cornell, and thus highly individualized programs of study can be worked out between a student and his faculty advisers. Graduate students in mechanics often choose courses from the Fields of Structural Engineering, Mechanical or Aerospace Engineering,

Scattered light is used to investigate the internal stress distribution in a translucent sample.

Applied Mathematics, Mathematics, Applied Physics, and Physics to supplement their departmental courses.

Facilities

The Department of Theoretical and Applied Mechanics has well-equipped laboratories for experimental stress analysis and photoelasticity experiments, for work with vibrations and wave propagation, and for research in the dynamics of rigid bodies. The facilities of the Materials Science Center are available to students who are interested in the mechanics of materials.

The University's extensive computer facilities are vital to many research programs; they supplement departmental analog computers and a minicomputer which has proved valuable for rapidly solving simple problems.

Areas of Research

As examples of the research effort in the Field, some projects in the areas of solid mechanics, space mechanics, fluid mechanics, and biomathematics are described briefly below. In addition to this research, interdisciplinary studies are being actively pursued in cooperation with many other fields of the Graduate School. A few of these are: the dynamics of fruit harvesting to help agricultural engineers; quantitative measurement of bovine health for animal scientists, and other research into the mechanics of biological materials; studies of fiber-reinforced materials with materials scientists and civil engineers; the mathematical structure of self-reproducing machines; mathematical investigations of ecological as well as population evolution problems; and work on the origin and dynamical evolution of the natural satellites of the planets. A complete file of recent student theses and faculty publications is available in the office of the Field.

It should be noted that Professors Block, Dunn, Jenkins, Levin, Ludford, and Rand are also members of the Field of Applied Mathematics and that some of their research studies constitute contributions to that discipline as well as to theoretical mechanics.

Solid Mechanics

Research in a wide variety of newly developing aspects of solid mechanics is being conducted. Fundamental work on the mechanics of composite materials has been carried out at Cornell for several years. Models have been developed for the plastic failure of composite structures, and other experimental and theoretical work has involved the microscopic study of fibers embedded in an elastic matrix. Interesting problems in elasticity, involving particularly the interaction of the elastic media with electromagnetic and thermal fields, have recently been investigated. Other studies involve the mechanics of structured continua and liquid crystals. A particularly vigorous research effort combines the techniques of ultrasonics with those of spectral analysis to investigate experimentally, and then interpret theoretically, the structure of complex engineering materials and materials of geophysical interest.

Professors Conway, Jenkins, Lance, Pao, Robinson, and Sachse are involved in solid mechanics research. Professors Pao and Conway are members of the Materials Science Center. Some of the recent publications resulting from this research are:

Conway, H. D.; Engel, P. A.; and Lee, H. C. 1972. Force-time investigations for the elastic impact between a rigid sphere and a thin layer. *International Journal of Mechanical Sciences* 14:523.

Jenkins, J. T. 1972. On a material coefficient in cholesteric liquid crystals. *Molecular Crystals and Liquid Crystals* 18:309.

Sachse, W. H., and Green, R. E., Jr. 1970. Deformation rate effects on the attenuation during loading, unloading and reloading of aluminum crystals. *Journal of Physics and Chemistry of Solids* 31:1955.

Thesis work in this area includes:

Chang, C. I. 1971. Mechanical Properties of Fiber Reinforced Composites. Ph.D. thesis. (Professor Conway.)

Helfinstine, J. 1972. Two Approaches to Yielding of Fiber Reinforced Composite Materials. Ph.D. thesis. (Professor Lance.)

Hutter, K. 1973. Electrodynamics of Deformable Continua. Ph.D. thesis. (Professor Pao.)

Kuo, E. 1973. Elastic Torsion of Composite Materials. Ph.D. thesis. (Professor Conway.)

Space Mechanics

Problems in the mechanics of the solar system and space flight mechanics have particular significance in view of the recent achievements of the national space program. Studies at Cornell are involved with the questions of where and how to place spacecraft for optimal trajectories—those, for example, which minimize fuel expenditure—and for positions which will be stable or quasi-stable in the earth-moon gravitational system. Other research has been concerned with the rotation of celestial bodies, including the earth, pulsars, natural satellites and asteroids, and the dynamics of members of the solar system.

Research in this area is directed by Professors Dunn, Rand, and Burns; the latter is also a member of the Field of Astronomy and the Center for Radiophysics and Space Research. The kinds of problems under study are suggested by the following examples of recent faculty publications and graduate theses:

Burns, J. A. 1972. Dynamical characteristics of Phobos and Deimos. *Reviews of Geophysics and Space Physics* 10:463.

The nonlinear vibrations of a clamped elastic plate are being studied in a graduate research project.

Rand, R. H., and Podgorski, W. 1972. Geometrical dynamics: a new approach to periodic orbits around L_4. *Celestial Mechanics* 6:416.

McAdoo, D. C. 1973. Asteroid Rotations and Their Implications. M.S. thesis. (Professor Burns.)

Fluid Mechanics

Cornell is internationally known for its basic research in magnetohydrodynamics and fluid dynamics. Current studies of the flow of conducting fluids in ducts may lead to efficient and clean new methods of power generation. The interactions of electromagnetic fields with continuous media, also under study, have many exciting technological applications. In basic research, the mathematical nature of boundary layer flow and stagnation point flow is being investigated in detail, and in a more recently initiated study, the phenomenon of rotating flows is being explored.

Professors Jenkins and Ludford direct research in this area. Recent projects have yielded the following representative publications and theses:

Jenkins, J. T. 1973. A theory of magnetic fluids. *Archive for Rational Mechanics and Analysis* 46:42.

Ludford, G. S. S.; Hassard, B. D.; and Chang, T. S. 1972. An exact solution in the stability of MHD Couette flow. *Proceedings of the Royal Society of London A* 327:269.

Olunloyo, V. O. 1972. Shear Flow Past a Flat Plate. Ph.D. thesis. (Professor Ludford.)

Walker, J. S. 1970. Three-dimensional Magnetohydrodynamic Flow in Rectangular Ducts Under Strong Transverse Magnetic Fields. Ph.D. thesis. (Professor Ludford.)

Biomechanics, Biomathematics, Bionics, and Robots

Research in this area of theoretical and applied mechanics has two goals. One is to study biological systems and their organization in order to devise improved engineering systems. The other is to use analytical engineering techniques to improve the understanding of biology and the interactions of biological systems. In research with self-learning machines, the objective is to comprehend more fully the way in which humans learn as well as think. An active area of work involves pattern recognition; attempts are being made to devise electronic means of identifying patterns for the purpose of obtaining a clearer understanding of the brain and for possible technological application. Substantial studies are concerned with mathematical description of ecological systems to aid in predicting the consequences of man's actions on his environment.

Professors Block, Dunn, Rand, and Levin are active in this area; the latter is also a member of the Field of Ecology and Systematics. Examples of publications and graduate theses in this subject are:

An air track is used in a graduate laboratory to study wave propagation along a chain of several coupled masses.

Block, H. D., and Ginsberg, H. 1968. The psychology of robots. *Psychology Today* 1(11):50. Reprinted in 1969 in *Readings in psychology today*, p. 36, Delmar, California: CRM Books; and in 1970 in *Readings in experimental psychology today*, p. 11, Delmar, California: CRM Books.

Levin, S. A. 1972. A mathematical analysis of the genetic feedback mechanism. *American Naturalist* 106:145.

Rand, R. H., and Cooke, J. R. 1973. A mathematical study of resonance in intact fruits and vegetables using a 3-media elastic sphere model. *Journal of Agricultural Engineering* 18:141.

Bezdek, J. 1973. Fuzzy Mathematics in Pattern Classification. Ph.D. thesis. (Professor Dunn.)

Faculty Members and Their Research Interests

Henry D. Block, Ph.D. (Iowa State): *applied mathematics; bionics and robots*

Joseph A. Burns, Ph.D. (Cornell): *celestial mechanics; planetary dynamics*

Harry D. Conway, Ph.D. (London), Sc.D. (Cambridge): *isotropic and anisotropic elasticity; plates and shells; impact*

Edmund T. Cranch, Ph.D. (Cornell): *dynamics of shells; wave propagation in solids*

Joseph C. Dunn, Ph.D. (Adelphi): *applied mathematics; optimal control theory; pattern recognition*

James T. Jenkins, Ph.D. (Johns Hopkins): *continuum mechanics; liquid crystals*

Herbert H. Johnson, Ph.D. (Case Western Reserve): *fracture; dislocation mechanics; fatigue*

Richard H. Lance, Ph.D. (Brown): *engineering plasticity; numerical methods; systems analysis*

Simon A. Levin, Ph.D. (Maryland): *applied mathematics; mathematical ecology*

Geoffrey S. S. Ludford, Ph.D., Sc.D. (Cambridge): *applied mathematics; fluid mechanics; magnetohydrodynamics*

Yih-Hsing Pao, Ph.D. (Columbia): *wave propagation in solids; magnetoelasticity; vibrations*

Richard H. Rand, Sc.D. (Columbia): *dynamical systems; biomechanics*

David N. Robinson, Ph.D. (Brown): *viscoelasticity; dynamical plasticity; experimental stress analysis*

Wolfgang H. Sachse, Ph.D. (Johns Hopkins): *mechanics of materials; nondestructive testing techniques*

Further Information

Further information may be obtained by writing to: Graduate Field Representative, Theoretical and Applied Mechanics, Thurston Hall, Cornell University, Ithaca, New York 14850.


CAT

The Professional Engineering Degrees

One of the two main branches of graduate education in engineering and applied science at Cornell leads to the professional, field-designed Master of Engineering degrees. The M.Eng. program is distinctly different from the research-oriented Master of Science program in the traditional M.S.-Ph.D. branch of graduate study.

The main purpose of the M.Eng. program is to prepare engineering students for professional practice in an increasingly technological society. Professional effectiveness requires technical competence of an extent and quality that is difficult to develop in a four-year undergraduate program; in addition, it requires an understanding of the interaction of engineering activities with economic, political, environmental, and social forces and considerations. The M.Eng. program at Cornell seeks to meet these needs by providing a course of study that stresses advanced work in a particular area of applied engineering, with a view toward successful practice in the contemporary world. The program emphasizes participation in a specific design project and the development of competence in solving complex, realistic engineering problems.

The eleven field-designated Master of Engineering degrees awarded by Cornell are:

M.Eng. (Aerospace)

M.Eng. (Agricultural)

M.Eng. (Chemical)

M.Eng. (Civil)

M.Eng. (Electrical)

M.Eng. (Engineering Mechanics)

M.Eng. (Engineering Physics)

M.Eng. (Industrial)

M.Eng. (Materials)

M.Eng. (Mechanical)

M.Eng. (Nuclear)

A group of Master of Engineering (Civil) students recently designed a regional water-supply system.

Most Master of Engineering degree holders enter industrial or other professional practice, but the program also provides an excellent practical base for further graduate study leading to a research-oriented Ph.D. degree.

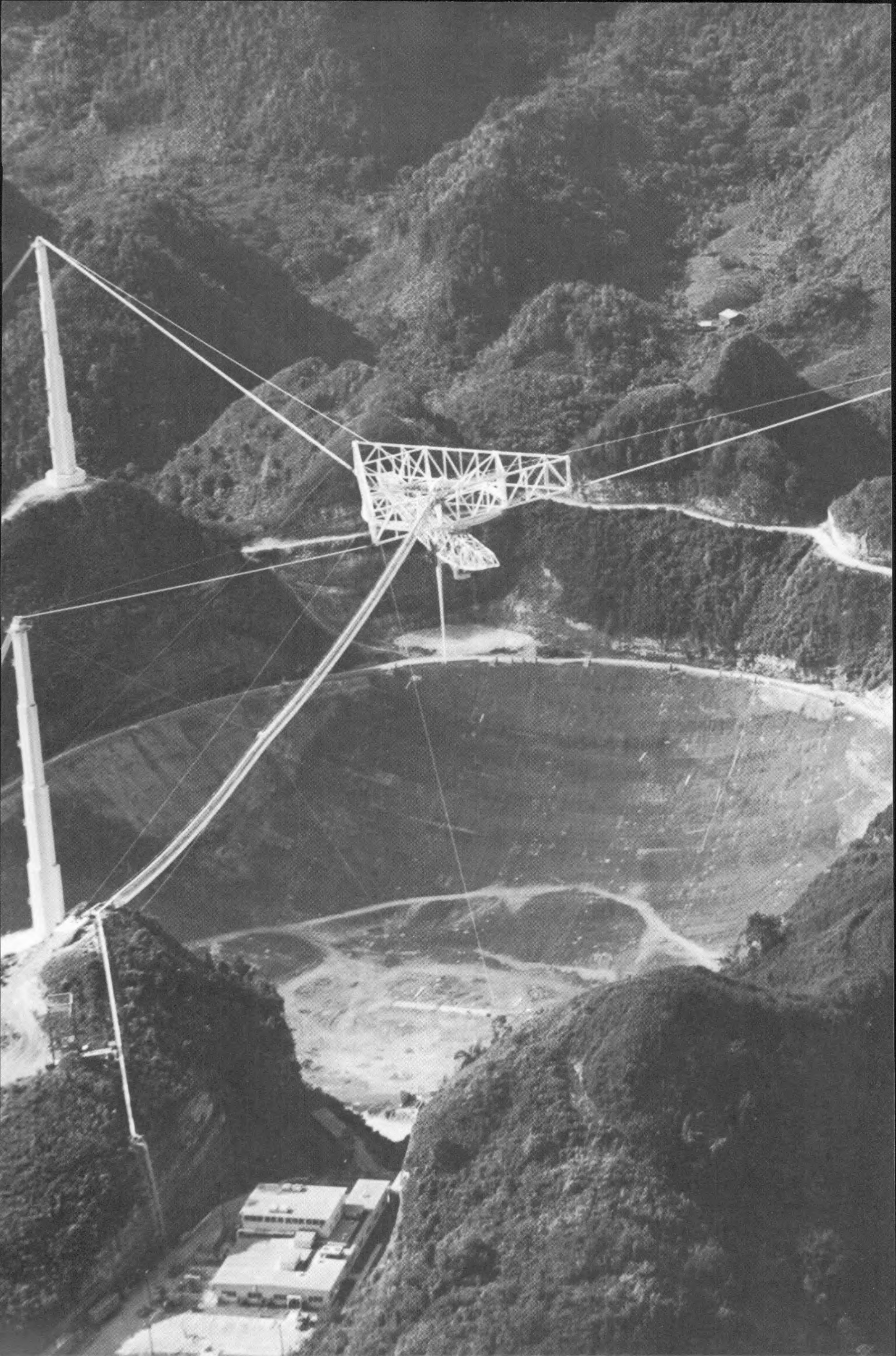
For some years, this program has been a leading option for Cornell baccalaureate engineering graduates; about one-third elect to continue their studies in this fifth-year program. The course of study in each of the eleven engineering fields is designed to continue an undergraduate major. The program is also suitable for baccalaureate degree holders from engineering schools other than Cornell.

Requirements for the degree include thirty credit hours of advanced technical work, normally completed in two semesters. The programs for the different fields differ considerably in detail, but all require three to twelve credit hours of work on a design project, which is often conducted with the assistance or under the direction of industrial personnel or consultants. Some design projects are carried out during a four-week period of concentrated full-time effort; others are spread over two semesters.

Financial aid in the form of scholarships and loans is available. Some half-time teaching assistantships and a few fellowships are also open to Master of Engineering degree candidates.

Further Information

Additional information and application forms may be obtained by writing to the Chairman, Graduate Professional Engineering Programs Committee, 323 Upson Hall, Cornell University, Ithaca, New York 14850. It would be helpful for correspondents to indicate the fields of engineering in which they have an interest.



Interdisciplinary Centers at Cornell

Cornell University maintains several interdisciplinary research centers that are of great significance in many applied science and engineering projects. These are of interest to prospective students in the various graduate fields in that their research efforts might be closely identified with those of a center, or their research activities might be conducted in the associated laboratories. These centers do not formally admit graduate students; those interested in the areas encompassed by an interdisciplinary center should apply for graduate admission through a related graduate field and work with the center through their supervising professors.

Center for Environmental Quality Management

An interdisciplinary research and graduate training focus for those interested in issues pertaining to the control of the environment is provided by this Center. Since it has become increasingly apparent that approaches which concentrate on limited objectives are insufficient to cope with the complexities of contemporary and anticipated problems involving the environment, the Center is designed to facilitate broad approaches involving many disciplines.

The scientific aspect of environmental quality management involves the biological, physical, and social sciences and serves to provide information that will enhance the development of optimal public policy decisions. The methods of the management sciences, such as systems analysis, operations research, computer science, and statistical inference, provide an initial base of quantitative methods for analysis of problems with an important bearing on environmental quality.

A recent addition to the Center is the Interdisciplinary Research Group, which consists of five full-time Cornell faculty members designated as Center Fellows for an academic year. The purpose of the Group is to bring together experts in areas related to environmental concerns so that a coordinated investigation of crucial problems can be made. This Group is interested in working with graduate students in a variety of fields of study and research.

The Center attempts to assist in financial and scholarly support for students who are interested in interdisciplinary studies pertaining to environmental management. Those who plan to pursue graduate work in areas of interest to the Center are advised to indicate this when they apply for Graduate School admission. The graduate Fields of study most closely related to the interests of the Center are Civil and Environmental Engineering, Environmental Quality, and Water Resources.

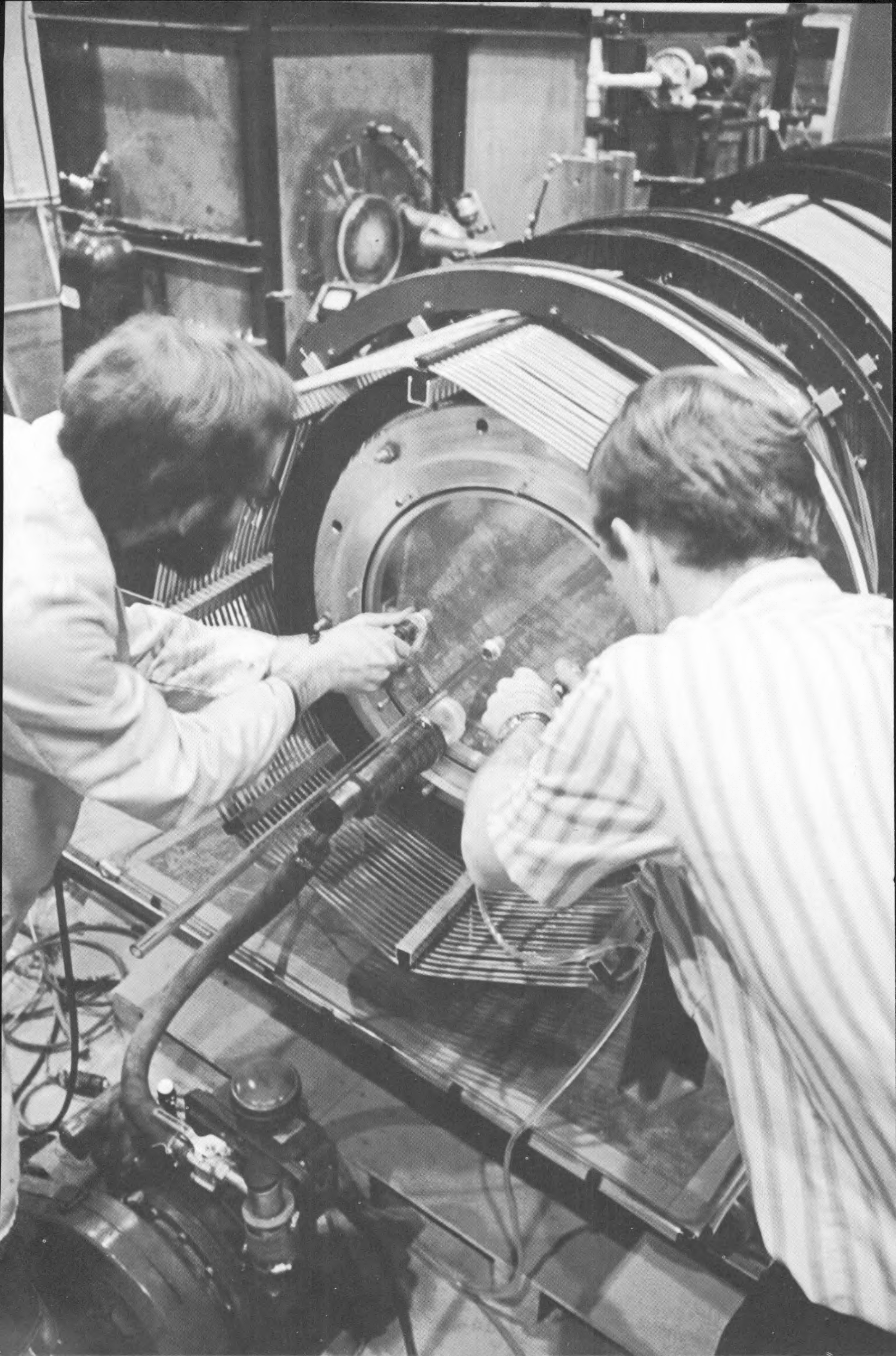
More detailed information may be obtained by writing to Professor Walter R. Lynn, Director of the Center for Environmental Quality Management, Hollister Hall, Cornell University, Ithaca, New York 14850.

The world's largest radio-radar telescope is used by Cornell research workers at the National Astronomy and Ionosphere Center in Puerto Rico, a facility operated by Cornell.

Center for Radiophysics and Space Research

This Center provides facilities for research in astronomy and the space sciences that is carried out by several departments in the University, and facilitates contact and cooperation among the various disciplines. Graduate students interested in space science research may apply for Graduate School admission through a number of graduate Fields of study. Fields of engineering and applied science that draw on the resources of the Center are Aerospace Engineering, Applied Physics, and Electrical Engineering.

The Center's facilities on the Cornell campus include an infrared laboratory, a lunar laboratory, and a laboratory for planetary studies. Large optical telescopes in the southwestern United States are available, and plans are being made for additional optical telescope facilities for a group of New York State universities, including Cornell. Facilities for research in radio-radar astronomy are available



through the National Astronomy and Ionosphere Center, which is operated by Cornell in Arecibo, Puerto Rico. This Center has the world's largest radio-radar telescope, with an antenna 1,000 feet in diameter. Facilities of Sydney University in Australia are also available to Cornell students and faculty through the Cornell-Sydney University Astronomy Center, a cooperative venture of the two universities.

Further information may be obtained by writing to: Secretary, Center for Radiophysics and Space Research, Space Sciences Building, Cornell University, Ithaca, New York 14850.

Center for Urban Development Research

This Center is an interdisciplinary facility serving the entire University by developing and supporting programs in urban and regional studies. The graduate Fields most directly involved in the Center are Regional Science and Urban Studies, but students enrolled in the graduate Field of Civil and Environmental Engineering may also find its resources useful.

The Center provides an intellectual and physical focal point for urban and regional studies, and furnishes working space, conference facilities, and administrative support for faculty members and graduate students who are engaged in urban-oriented research, training, and service programs. It is able to offer a limited number of research assistantships to graduate students of Center faculty members.

The Center also seeks to encourage new educational developments and new forms and combinations of interdisciplinary, problem-oriented research. It publishes the results of research conducted under Center auspices and also other papers of potential interest to scholars and professionals working in the various areas of the urban and regional fields. As an aid to faculty and interested students, the Center also publishes the annual *Directory of Courses Relating to Urban Problems.*

Further information about the Center may be obtained by writing to Professor Gordon P. Fisher, Director, Center for Urban Development Research, 726 University Avenue, Cornell University, Ithaca, New York 14850.

In the Laboratory of Plasma Studies, researchers work with a magnetic coil configuration for an experiment that applies electron beam accelerators to the generation of "electron coils" for possible fusion applications.

Laboratory of Plasma Studies

This laboratory was established as an interdisciplinary center for research in plasma physics and lasers. Active areas of research include controlled fusion, intense beams of relativistic electrons, basic plasma physics, theory of high-temperature plasmas, molecular lasers, chemical lasers, and laser-produced plasmas. A variety of both large and conventional laboratory-scale facilities is provided.

Faculty members associated with the Laboratory represent several graduate fields, among which are Aerospace Engineering, Applied Physics, Chemistry, Electrical Engineering, Mechanical Engineering, and Physics. Graduate students normally become affiliated with the Laboratory by choosing to do research with a faculty member engaged in Laboratory projects. During the Laboratory's first four years of existence, its research projects led to the completion of sixteen Ph.D. and five M.S. theses.

Financial assistance in the form of graduate research assistantships is available in limited quantity and is obtained directly from the Laboratory; fellowships are available through the normal Graduate School channels.

Further information may be obtained by writing to Professor Peter L. Auer, Director of the Laboratory of Plasma Studies, Upson Hall, Cornell University, Ithaca, New York 14850.

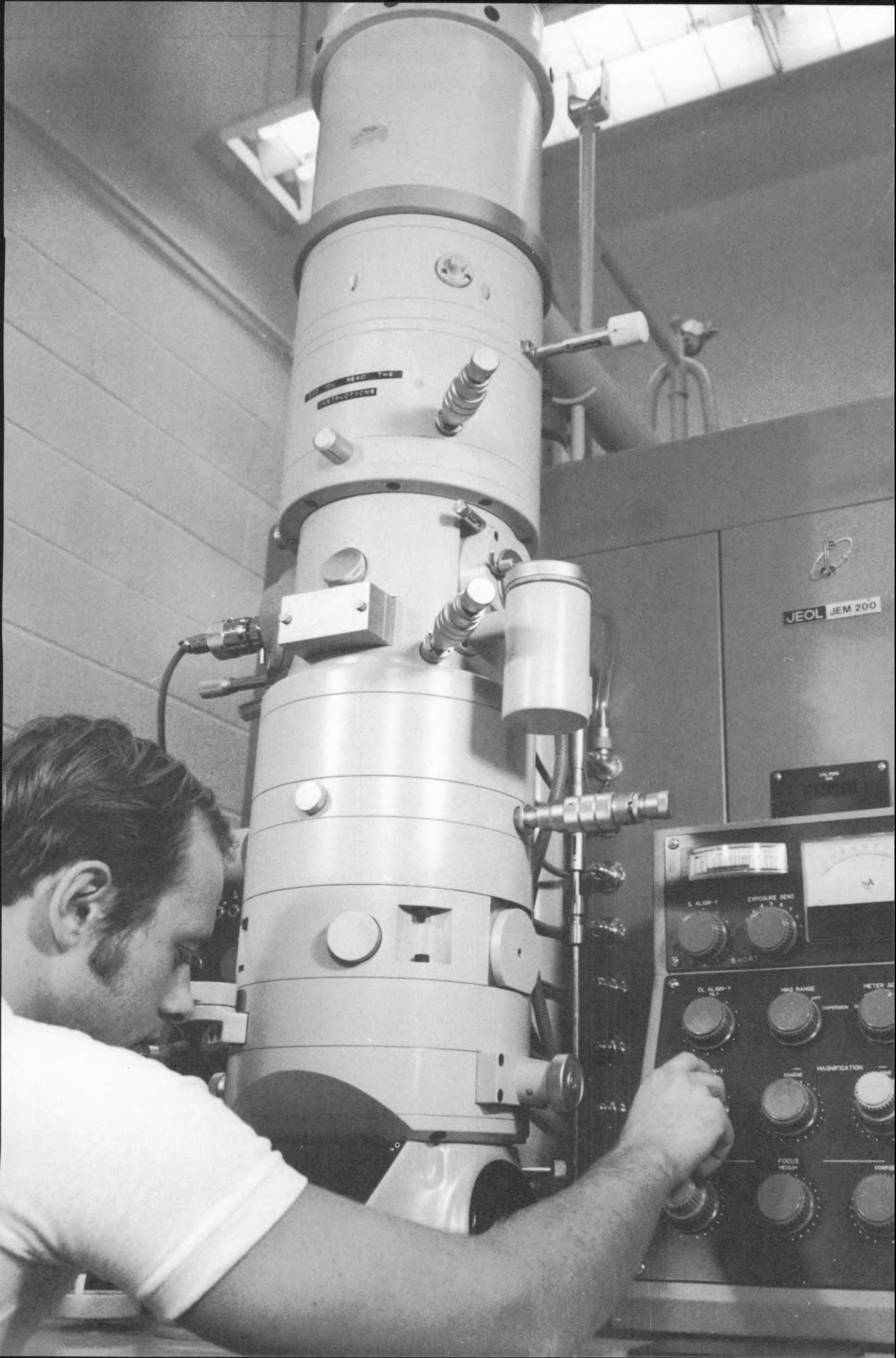
Materials Science Center

This Center facilitates graduate research and training in many phases of the science of materials. It provides a number of special laboratories containing highly sophisticated equipment that is made available to researchers in many areas, including applied physics, chemistry, electrical engineering, materials science and engineering, mechanics, metallurgy, and physics. In some cases new equipment needed for specific thesis research projects and the assistance of technicians can be provided. The Center is also able to provide financial assistance in the form of research assistantships.

The laboratories at the Center are for materials preparation, metallography, X-ray diffraction, electron microscopy, electronics, low-temperature work, chemical analysis, nonmetallic crystal growth, and laser development. Each of these laboratories is under the direction of a faculty member and staffed with trained technicians, so that researchers receive expert guidance and assistance.

Most of the Materials Science Center facilities are located in Clark Hall of Science, the University's center for solid state and applied physics, and Bard Hall, the Department of Materials Science and Engineering building.

Additional information may be obtained by writing to: Director, Materials Science Center, 627 Clark Hall, Cornell University, Ithaca, New York 14850.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Water Resources and Marine Sciences Center

This 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 involves faculty and graduate students in the sciences, engineering, agriculture, law, economics, government, regional planning, and public health.

As part of its responsibilities, the Center undertakes and supports water resources research involving these various fields, and it publishes the results of research. It encourages new combinations of disciplines in research and training which can be brought to bear on water resource problems, and it develops and operates central facilities.

The graduate Field of engineering that is most involved with the Center is Civil and Environmental Engineering; the Center is located in Hollister Hall, the main facility of the School of Civil and Environmental Engineering. Also, the Field of Water Resources, which offers an interdisciplinary minor program of study available to graduate students, is closely related to the Center.

Further information about the Center may be obtained by writing to Professor Leonard B. Dworsky, Director of the Water Resources and Marine Sciences Center, Hollister Hall, Cornell University, Ithaca, New York 14850.

This JEM 200 kV electron microscope is among the instruments made available to graduate students by the Materials Science Center.

General Information

Cornell is an internationally known university consisting of fourteen colleges and schools which enroll about 15,000 students, including 3,500 in the Graduate School. A unique feature of the University is the combination of privately financed and state-supported units, a circumstance that fosters Cornell's century-old concept of education in all subjects for all qualified students. The individual student is afforded an unusually rich and diverse background of academic life.

The College of Engineering has a total enrollment of about 2,750 and a faculty of about 200. It is organized into schools, departments, and graduate fields. in general, the faculty of a school or department is responsible for undergraduate education and for the professional M.Eng. degree programs, and the faculty members associated with the various graduate fields supervise the M.S. and Ph.D. degree programs.

Facilities

Cornell University maintains more than ninety major buildings on its 740-acre Ithaca campus. The College of Engineering is centered in ten modern buildings in the area known as the Engineering Quadrangle, although some of its activities are carried out at other campus locations, in buildings such as Clark Hall, which is the University's center for solid state and applied physics, and the Space Sciences Building.

Cornell's outstanding library system is comprised of two large central facilities supplemented by a number of specialized libraries in buildings throughout the campus. The entire collection, including more than four million volumes, is available to all students. The College of Engineering library, which has approximately 125,000 books and periodicals, and the physical sciences and mathematics libraries are especially useful to engineering and applied sciences graduate students.

Of special importance to many graduate students is the University's computing facility. At the present time this consists of a multiprocessor complex of IBM 360 systems, including a central 360/65 system and satellite computers at three different campus locations. The College of Engineering is served through two of these satellite stations, as well as by a number of teletypewriter terminals. The 360 system is to be replaced in late 1974 by an IBM 370/168.

Among the attractions of the Finger Lakes region are three state parks situated within a few miles of the Cornell campus.

Location of the University

Most of the schools and colleges of the University are located in Ithaca, at the southern end of the Finger Lakes region of upstate New York. The population of the greater Ithaca area, including students, is about 40,000. Public transportation to Ithaca is provided by Allegheny Airlines and the Greyhound bus lines.

The Cornell University Medical College, the Graduate School of Medical Sciences, and the Cornell University-New York Hospital School of Nursing are located in New York City. The University also operates the New York State Agircultural Experiment Station in Geneva, and the National Astronomy and Ionosphere Center in Puerto Rico.

Admission

Application for enrollment in any field of graduate study at Cornell is made through the Graduate School of the University, and acceptance is determined by the faculties of graduate fields. Application forms may be obtained through the Graduate School or a particular graduate field.

It is the policy of Cornell University actively to support equality of educational opportunity. No student shall be denied admission to the University or be discriminated against otherwise because of race, color, creed, religion, national origin, or sex.

It may be helpful for applicants, especially those who intend to apply for fellowships and scholarships, to take the Graduate Record Examination Aptitude Test (Verbal and Quantitative) and the Advanced Engineering Test and have scores sent to the

Graduate School. Information about these tests may be obtained from the Educational Testing Service, Princeton, New Jersey 08540.

Financial Aid and Employment Opportunities

Financial aid in the form of teaching, research, or residence hall assistantships, fellowships, scholarships, and loans is available to graduate students.

An applicant for admission to an M.S. or Ph.D. degree program will receive detailed information about available financial aid along with his application materials, and should indicate a request for aid on his application form. A prospective student in one of the M.Eng. degree programs should file a separate application for financial aid along with his admission application. Addresses for obtaining the appropriate materials are given at the end of this *Announcement.*

It may also be noted that there are fellowships and scholarships offered by state and national governmental agencies, by foundations, and by private parties. The Cornell University Career Center maintains a collection of pertinent reference materials on such sources of financial aid. A useful reference book is Norman Feingold's *Scholarships, Fellowships, and Loans.*

Opportunities for part-time employment are sometimes available to graduate students through their own departments, and a part-time employment service is maintained by the Office of Scholarships and Financial Aid. Wives of students frequently find employment at Cornell through the University's Personnel Office, or with local businesses or industries, professional offices, schools and colleges, public service agencies, and the hospital. A New York State Employment Office is located in Ithaca.

Extracurricular Activities

A wide variety of cultural events, including lectures, special programs and conferences, and music, drama, and film offerings, are available at Cornell. Ithaca residents also have the opportunity to attend theatrical and musical events at Ithaca College.

Programs in religious affairs at the University include information, counseling, and referral services as well as ministries in many religious groups. A Center for Religion, Ethics, and Social Policy is a nondenominational, educational unit.

The Sage Graduate Center supplements the three student unions at Cornell in providing opportunity for social and recreational activities. Graduate students are also welcome to join undergraduates in student activities such as intramural sports, drama, and the production of campus publications. The various University musical groups and many of the more than one hundred organizations on campus are open to graduate students. Wives of graduate students are frequently active in their own special organizations. There is also an organization for foreign students and their families.

Extensive recreational facilities, including those for swimming, ice skating, golf, bowling, and tennis, are available on campus. Graduate students are also eligible for all intramural and informal sports at the University. Additional opportunities for outdoor sports and recreation are available in the surrounding area.

A popular winter sport for Cornell students is skiing, available at several nearby areas.

Housing and Dining

Graduate dormitory housing and apartments for married students are available on campus, and help in obtaining off-campus housing is offered. Detailed information about housing is sent along with requested application materials.

The University has no dining requirements, but offers some optional arrangements and provides a number of dining services on campus. Among these facilities is a dining service at Sage Graduate Center that is available to all graduate students and faculty members.

Further Information

The *Announcement of the Graduate School* and the *Announcement of General Information* are useful to prospective Cornell graduate students and should be consulted for additional information on admission, financial aid, and degree requirements. Information about facilities and programs in the various schools and departments of the College of Engineering is included in the *Announcement of the College of Engineering.* Applicants for graduate study may also request the *Announcement of the Graduate School: Course Descriptions.* Copies of these publications may be obtained by writing: Cornell University Announcements, Day Hall, Ithaca, New York 14850.

In addition, further information about specific graduate programs may be obtained by writing to the graduate field representative (for M.S. or Ph.D. degree programs) or to the Master of Engineering representative (for the M.Eng. degree programs) in the academic area of interest. Information about the M.Eng. degrees is available also through the Graduate Professional Engineering Programs Committee. Addresses are given at the end of the appropriate sections in this *Announcement.*

Application materials for the Graduate School, including financial aid information and request forms, may be obtained from the Sage Graduate Center, Cornell University, Ithaca, New York 14850. Admission and financial aid application forms for the Master of Engineering degree programs may be obtained by writing to: Graduate Professional Engineering Programs, 323 Upson Hall, Cornell University, Ithaca, New York 14850.