

National Science Foundation

Twenty-Eighth Annual Report for Fiscal Year 1978

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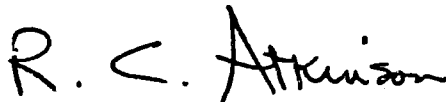
Letter of Transmittal

Washington, D.C.

DEAR MR. PRESIDENT:

I have the honor to transmit herewith the Annual Report for Fiscal Year 1978 of the National Science Foundation for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,

A handwritten signature in black ink that reads "R. C. Atkinson". The letters are cursive and fluid, with a large initial "R" and "A".

Richard C. Atkinson
Director, National Science Foundation

*The Honorable
The President of the United States*

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Science: New Pathways and New Promise

It is with continued confidence in the state of science in the Nation that I present this Annual Report of the National Science Foundation.

The report documents progress in the many areas of science and engineering supported by the National Science Foundation through its system of grants and contracts. In 1978 the progress was noteworthy. New programs linked efforts at universities, major research centers, and private industry. Basic research, research in applied science and science applications, and science education continued to move forward.

The importance of basic research to the Nation is clear. Our understanding of fundamental scientific principles—and the skill with which we apply them—affect both our productivity and our economic status in the family of nations. Not only technical innovations, but also many social benefits, derive directly or indirectly from our grasp of what the universe, our planet, and life are all about.

The record has been good. Through freely exercised creativity, fiscal strength, and superb management systems, the United States has long led the world in agricultural, industrial, and military innovation. To remain strong in a changing world environment, we know we must continue to make full use of our scientific research and development potential.

We have the resources to do so. In many scientific pursuits, instruments of great power and precision now perform hitherto impossible research tasks. During the past year advanced X-ray detectors speeded up the mapping of the crystal structure of enzymes, and by the end of

1978 an instrument combining a wide bore magnet with a Fourier transform spectrometer was ready for detailed studies of large, complex biomolecules. The year saw half of the 27 scheduled radio antennas at the Very Large Array (VLA) in New Mexico already in operation; their resolving power matches that of the largest optical telescope in existence.

Even familiar instruments were put to new uses. That versatile scientific tool, the laser, glues together chemical compounds, parts isotopes, and is being used in attempts to induce nuclear fusion. Last year, in a light-scattering experiment using a laser, chemists were able to measure the growth of cholesterol microcrystals, a phenomenon of obvious relevance to such medical problems as gallstones. Another laser confirmed an important theory of Albert Einstein. A third annealed semiconductors in a new process of great potential for electronics manufacturing.

The various branches of science liberally borrowed instruments and techniques from each other. The findings they produced advanced theories in seemingly unrelated scientific fields. Studies last year at the cellular level, for example, opened up new vistas in both plant pathology and the neurosciences.

The view of all sciences as increasingly one science does not suggest an actual regrouping of the different disciplines. But it has greatly enlarged our capacity for important discovery. With new instrumentation, improved computers, and better communication systems, scientific research in 1978 broadened our understanding of natural phenomena. The

scientific quest for the origins of life, matter, and the universe itself went unabated. Searching the galaxies for stars in different stages of their life cycles, astronomers determined the youngest found so far to be a mere 2,000-year-old child. And they pinpointed the most likely location of a supermassive black hole, in the constellation Cygnus.

While astronomers probed the skies, geologists and oceanographers drilled under the ocean, through the Ross Shelf in Antarctica, and into the Earth's volcanic surface to find out how our planet evolved. Atmospheric scientists, concerned with the envelope of gases that surrounds the Earth in the troposphere, took important steps toward understanding its chemistry. They also came closer to being able to predict the gigantic electrical discharges of the aurora borealis in the polar atmosphere.

This was clearly pure science—yielding us knowledge we would store for unknown future use. In other instances—such as research on the properties of materials like superconductors, polymers, and glass—basic research attracted attention because its potential for industrial use was evident.

There was also food. People involved in the production or nutritional content of food watched with interest research in biology and the various marine sciences. Cell biologists are attempting to learn how membranes regulate the ions that flow across them, since this process appears to establish patterns of growth and might even be used to control disease. Last year, a research team discovered that the flow of a current of calcium across cell membranes helps control biological development. On a different level, studies of coastal upwelling—the rise of nutrient-rich cold waters from the ocean's bottom to the surface—could help predict the distribution of plants and animals along the continental shelf. And while one of the few

watery places where some sort of food chain has not yet been confirmed is under the Ross Ice Shelf, krill, a shrimplike crustacean, continues to receive attention as a food resource in Antarctica.

We know that new knowledge will affect how we live in the future. And although we cannot predict the future with real certainty, we nevertheless are becoming better able to chart possible directions as an aid in our planning. Moreover, by examining the process of innovation and the impacts of scientific and technological development, we are gaining in understanding the consequences on our physical and social environments. NSF-supported studies in this far-reaching area will serve as a basis for U.S. policy positions at the United Nations Conference on Science and Technology in August 1979. At the same time, in smaller but no less important studies related to domestic policy, the Foundation is supporting inquiries into how to improve services of the U.S. Government at the Federal, State, and local levels.

The Nation requires highly qualified scientists to perform this valuable and needed research. The Foundation, which is also responsible for ensuring a continuing cadre of scientists and engineers for the future, is concerned that the possibility of a tightening academic job market may be dissuading some good students from preparing for science careers. In 1978, NSF expanded its science education programs at a level critical to youngsters making decisions about their future study courses—junior high school—and continued efforts to encourage more women, minorities, and the handicapped to enter science careers and to perform scientific research. It also continued its effort to increase public understanding of what modern scientists do, why they are doing it, and what they are learning.

The pages that follow in this report recount in detail more new and continuing undertak-

ings in research and education. The individual programs reflect both the spirit of our times and the legislation that shapes the National Science Foundation as a Government agency.

Above all, they demonstrate the need for strong Government support so that science may function efficiently in the interest of the Nation both now and for the times to come.

Richard C. Atkinson
Director

as well as in several aspects of engineering. However, there are also more subtle, but equally important, interactions between different subfields of mathematics; between mathematics, engineering, and the physical sciences; and between chemical subfields such as organic and inorganic chemistry. It is anticipated that this trend will continue in those areas where improved scientific progress can result.

Obviously, the style in which research is conducted varies according to the specific needs of each discipline. The spectrum of support provided by NSF across the programs in mathematical and physical sciences, and engineering ranges from individual research projects to major facilities involving large numbers of investigators. Most of the awards are made to individual or small groups of faculty who, together with their graduate students and postdoctoral associates, carry out projects in their own laboratories. This mode of operation forms the traditional backbone of fundamental scientific and engineering research in the Nation's universities. At the same time, the essential requirements of some disciplines for major facilities, such as high energy physics accelerators, and the increasing cost, sophistication, and capabilities of modern research instrumentation, require alternative institutional arrangements for their most effective use. NSF therefore supports a number of national user facilities, including the Synchrotron Radiation Facilities at Stanford and Wisconsin, the National Magnet Laboratory at MIT, the Microfabrication Facility at Cornell, and the National Center for Computation in Chemistry at Berkeley. In addition, NSF supports several regional instrumentation facilities at different university locations and 13 interdisciplinary materials research laboratories.

Unsolicited research proposals are initiated by individual or groups of scientists and engineers who wish to undertake a particular research proj-

ect. The proposals are submitted on behalf of these investigators by their institutions, primarily colleges and universities, to one of 47 research programs in the mathematical and physical sciences, and engineering. Proposals are reviewed by members of the "peer" community (drawn from academic, industrial, and government institutions) who are expert in the corresponding areas. The principal criteria for evaluation are the scientific merit of the research proposed and the

capabilities of the investigators to carry out that research. During fiscal year 1978 some 7,900 research proposals were received and evaluated by more than 30,000 reviewers. These resulted in 4,044 awards for research support to more than 5,000 scientists and engineers. In addition, more than 4,700 graduate students had an opportunity to study and carry out research under the supervision of many of the Nation's best scientific and engineering researchers.

Physics

In its search for the fundamental laws governing matter and energy, the discipline of physics operates over a range of scale that encompasses the most elementary and minuscule constituents of matter—subnuclear quarks and leptons—and the largest aggregation imaginable—the universe. Physicists seek to incorporate all phenomena across this range into a single, self-consistent interpretation—a unified theory—based on detailed knowledge of the fundamental forces acting upon components of the micro- and macroworlds.

The pursuit of this goal is through experimental and theoretical research in various subfields of the discipline: elementary particle physics (sometimes referred to as high energy physics); nuclear science (which encompasses intermediate energy physics and nuclear physics); atomic, molecular, and plasma physics; and gravitational physics.

The type of research necessary to gain new knowledge varies from one subfield of physics to another. In elementary particle physics, which involves the search for new subnuclear states of matter, experimentalists study the interactions of high energy particles impacting on fixed targets or in colliding beams in accelerators. Accelerator facilities are large and com-

plex, usually beyond the capability of a single university to handle. Consequently, the predominant mode of research is that of university-based groups gathering data at centralized, national facilities, such as Department of Energy-supported facilities at Fermilab, Stanford Linear Accelerator Center, Brookhaven National Laboratory, and Argonne National Laboratory, and the NSF-supported Cornell Electron Storage Ring. Frequently, a single experiment will be so complex as to require collaborations among groups from several universities and from the laboratories themselves. Experiments may take years from conception through data gathering and analysis to publication of results.

Nuclear science explores nuclear structure with particle probes that reveal the positions and motions of neutrons and protons in nuclei and uses the nucleus as a laboratory to study symmetry and conservation laws and strong and weak forces. Experiments are performed on accelerators of energies somewhat lower than those used for elementary particle physics research. There is a trend toward use of centralized facilities for experiments in the energy range of about 100 MeV (million electron volts) to 1 GeV (billion electron volts). This range represents the generally ac-

cepted lower energy limit for elementary particle physics research. NSF supports a national facility, the Indiana University Cyclotron Facility, for research using light ions of energies about 200 MeV. Lower energy accelerators generally fit easily into a university environment and can be operated as in-house facilities primarily used by a local research group.

Atomic, molecular, and plasma physics and ground-based gravitational physics experiments are usually of a scale that fit within a university laboratory and can be pursued by small groups of faculty, research associates, and students. Lasers have provided a revolution in the capability for precise, fundamental measurements on atoms and molecules, and they promise to provide a new generation of detectors for gravitational radiation as well.

Theoretical physics is the exploration of a conceptual, mathematical framework within which the results of experiments are interpreted and new experiments are suggested. This work is pursued primarily by individuals working alone or in small groups, although certain cross-subfield problems may require concerted efforts from a large number of theorists working together. One of the most exciting developments of recent years is the emergence of hints that phenomena previously considered separately, such as the strong, electromagnetic, weak, and gravitational forces, can be described in a few, unified theories. Physics has continuously contributed new fundamental understanding of matter at all levels of aggregation to other fields of science and has provided the underpinnings for many current advances in science and technology.

Quark Confinement

In 1963, Murray Gell-Mann and George Zweig at the California Institute of Technology proposed that the properties of elementary particles—neutrons, protons, pi mesons, etc.—could be understood if the particles

were made up of combinations of three fundamental point-size particles called quarks. During the intervening 15 years the number of proposed quarks has been expanded from three to five or more, but it is still possible to understand particle properties in a remarkably simple fashion in terms of the quark composition of the particles.

Nevertheless, a free quark has never been observed, even in the ultra-high-energy accelerators at Fermilab in Illinois and CERN in Geneva. This has led many physicists to speculate that perhaps quarks are more or less permanently trapped inside elementary particles. Until recently this idea, although shared by many physicists, had not been shown to follow directly from the widely accepted model of elementary particle interactions—so-called quantum chromodynamics. However, over the past several years, work by Curtis Callan and David Gross at Princeton University and Roger Dashen at the Institute for Advanced Study has done much to clarify the mechanism of “quark confinement.”

They have shown that in the theory of quantum chromodynamics, the “vacuum” (the state of matter that exists in the absence of quarks) is actually an enormously complex object—a superposition of many different states with identical energies but differing mathematical properties. One can imagine these different vacuum states as mountain villages, each of which is separated from its neighbor by high mountain peaks. In classical physics it would require a great expenditure of energy to travel from one village to another, but quantum mechanics permits an occasional direct route between villages by travel through the mountain.

The existence of such a direct route is usually described by the term “tunneling.” Tunneling processes connecting different vacuum states are taking place continuously at localized points in space and time. However, the Princeton theorists have suggested, when quarks are now added to this

vacuum state, a region in the vicinity of the quarks is created in which tunneling processes are no longer permitted. The existence of a phase of matter outside the quark region in which tunnelings continue to occur and another phase, without tunneling, near the quarks gives rise to an effective inward pressure that traps the quarks inside this interior region. This picture is remarkably similar to a very successful model of quark confinement suggested a number of years earlier by Kenneth Johnson and collaborators at the Massachusetts Institute of Technology. However, the MIT model included a “pressure,” added in a very ad hoc fashion rather than derived from first principles.

This progress towards an explanation of quark confinement in terms of quantum chromodynamics is gratifying, but one would also like to have some direct, detailed experimental evidence that quantum chromodynamics is indeed the correct theory of elementary particle interactions. Striking evidence of this kind has come very recently from an experiment at CERN. This experiment explored reactions in which a neutrino, an especially simple particle not made of quarks, penetrates a proton (or neutron), which presumably is made of them. What happens to the neutrino in such a reaction is a direct measure of the way in which a proton is made up of quarks and of the manner in which these quarks interact with one another.

The recent experiment focused on the changes in the quark composition of the proton as one probes ever smaller and smaller regions inside it with the neutrino. Some 5 years ago David Gross and a student, Frank Wilczek, at Princeton, and independently David Politzer, then a graduate student at Harvard, did work which led to the detailed predictions of quantum chromodynamics for these changes. The new experimental results agree impressively with these detailed predictions. This agreement lends support not only to the general characteristics

of quantum chromodynamics but to some of the rather specific assumptions of this theory as well.

Determining whether the picture of elementary particle structure suggested by quantum chromodynamics is the correct one will require a great deal of additional theoretical effort, but the stakes are high, and it is possible that we now have a glimpse at the underlying structure of matter.

Cluster Hierarchy

The large-scale distribution of matter in galaxies and clusters of galaxies has long been considered an important but tantalizing clue to the nature of the universe. It is the fossil evidence of the way the universe has been behaving, but what does it mean? Recent work by P. J. E. Peebles at Princeton University has revealed that the galaxy clustering has a remarkably simple pattern and one that seems naturally to arise by gravitational instability, the tendency for small disturbances to grow in a uniformly expanding universe.

Data on the distribution of galaxies have been accumulated by astronomers for the past several decades, but only with the development of high speed computers was it possible to sift through all the data and see that there is a simple underlying statistical pattern: a clustering hierarchy. The galaxies tend to appear in clusters, the clusters are grouped in clusters of clusters, and so on out to a scale of some 50 million light-years; on scales larger than that, the clustering continues but appears to be blending into a homogeneous distribution.

There is no division between levels of this hierarchy, so the pattern is not particularly evident to the eye. It is detected by statistical methods adapted from those used in the fundamental theory of a plasma (a gas of atoms and free electrons of the sort that would be used in a fusion power reactor). This same theory can be adapted to describe the process of formation of the clustering in the uniformly expanding big-

bang model of the universe. The theory suggests that the cluster hierarchy pattern would naturally develop as a result of the gravitational instability of the expanding universe. Thus it appears that we may understand part of the enigma of the clustering of matter and can analyze the process by which it happened.

The results so far are mainly a stimulus for new lines of research. There is still sharp debate on the amount of mass needed to drive the instability. This has the wider implication that, if a high mass is manifest here, it might also be enough to make the universe eventually stop expanding and collapse back to another big bang. The debate will be resolved by more detailed analysis of the theory of the instability and by more detailed examination of galaxy motions. This latter project is now in progress at several observatories and should yield an invaluable insight into the process of cluster formation.

Once we are convinced we understand the process, we will arrive at the puzzle of how the universe started expanding and how the instability was first triggered. Neither effect is predicted in general relativity theory. Rather, the expansion traces back to a singularity analogous to a black hole. The search for a more fundamental theory that will tell us what these singularities mean is one of the deepest problems in modern physics. It is by tracing clues like galaxy clustering that we hope to be guided to this most fundamental theory.

Illinois Superconducting Electron Accelerator

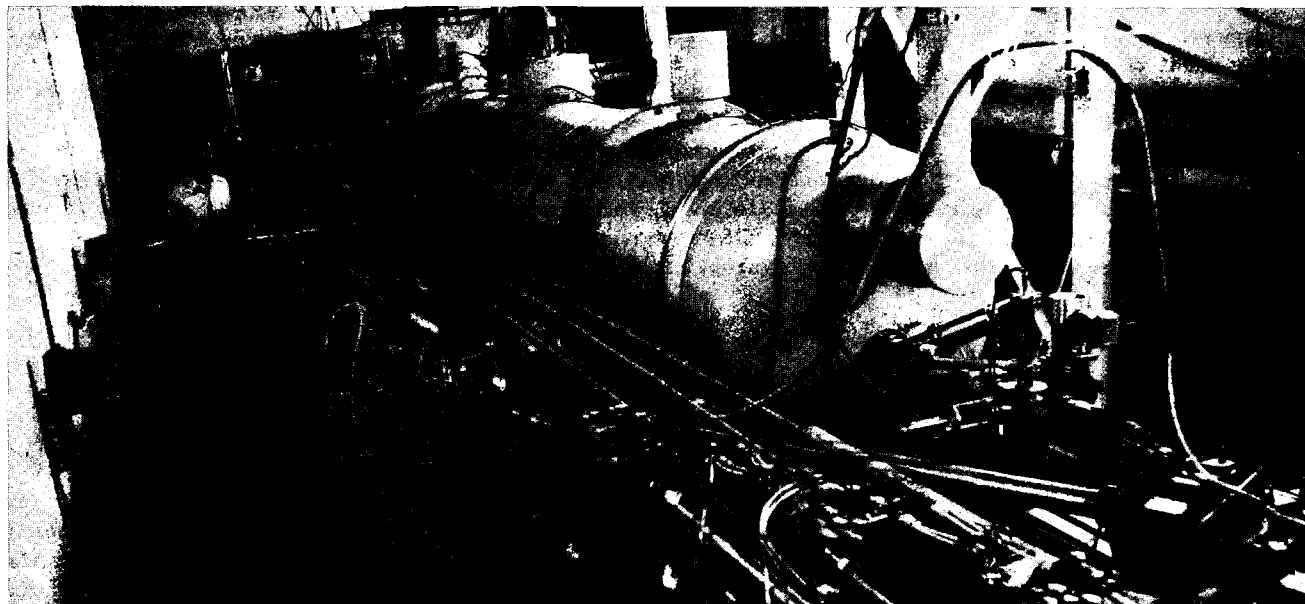
Particle accelerators providing the beams used for nuclear physics research are much like very special electrical sources, with voltages measured in millions of volts and currents measured in millionths of amperes. The phenomenon of superconductivity, in which the electrical resistance of special materials becomes zero at sufficiently low temperatures, has found an

important use in such accelerators as it has in some other electrical equipment. Because of the lack of electrical resistance within the accelerator, the current can be drawn steadily without the need to pulse the beam to permit the accelerator to cool between pulses.

This feature of a steady beam current has been much desired by nuclear physicists who want to count two or more particles ejected from beam targets. Use of the intermittent beams, with their high, instantaneous counting rate during each beam pulse, greatly increases the chance that measured coincident events actually are caused by unrelated reactions in the target.

In the superconducting electron linear accelerator at the University of Illinois, the accelerator itself is kept at only 2 degrees above absolute zero to induce the superconductivity. In order to capitalize on the qualities of the accelerator, the beam of electrons is recirculated through it (several times, via an array of beam pipes), gaining about 11 million electron volts on each pass. The final beam, up to 66 MeV in energy with the present system of recirculating magnets, is then available for experimental nuclear physics. A second stage, recirculating through another such accelerator, is under consideration. This would produce a beam energy of 280 MeV. (Much of the basic development of the superconducting linear accelerator has been carried out at Stanford University where a somewhat similar superconducting electron facility is in operation.)

An important experiment was recently completed at the University of Illinois facility by researchers from Illinois and Argonne National Laboratory. It used the photon (electromagnetic quanta) beams that may be produced with the high quality electron beam to investigate the aspects of the nucleus in which behavior like a quantum mechanical liquid drop is exhibited. Elastic and inelastic photon scattering at the energies chosen are dominated by the giant dipole reso-



Illinois Electron Accelerator. The large insulated tank contains the University of Illinois superconducting linear accelerator. Lloyd Young is one of the developers of this facility. The vacuum piping in the foreground allows the beam to be recirculated through the accelerator to raise its energy to 66 MeV.

nance, a very large-scale oscillation of the nucleus in which the neutrons move one way and the protons in the opposite direction to maintain the same nuclear shape. Since the inelastic scattering chosen involved a vibrational mode of the nucleus in which the neutrons and protons move together to change the shape of the nucleus, the experiment investigated the coupling between two major but rather different degrees of freedom. The results are not in quantitative agreement with the predictions of a standard nuclear model, and nuclear physicists must refine their concepts to account for the new data.

Isotropy of Space Revisited

Einstein's Theory of Special Relativity underlies the structure and achievements of modern science. One key assumption embodied in it is that space is isotropic in the absence of strong gravitational fields: that is,

there is no preferred "direction" or "velocity" in space with respect to which others are in some sense in motion. An equivalent statement is that the speed of light is the same in all directions. The classic experiment of Michelson and Morley in 1887 that verified this actually predated Einstein's work. Relativity theory, however, gave a powerful new interpretation to the experiment beyond Michelson's original result: proving that space was isotropic to a precision of 3 parts in 10 billion. This was later improved in 1930 to 3 parts in 100 billion, using the same methods.

There was no further improvement in this experiment until the advent of the laser. The first experiment using this new technique improved the accuracy by a factor of three. The further potential of the method was assessed at the Joint Institute for Laboratory Astrophysics (JILA) at the University of Colorado, and a program was initiated there in 1971 by John Hall, taking advantage of JILA's broad ex-

perience in experimental and theoretical physics.

The JILA experiment locks one laser to an optical cavity, the length of which is a constant number of wavelengths of the laser light. The entire assembly—of laser and cavity—can be rotated at a rate of one turn each 10 seconds, while the light is fed out to be compared with the light of another stabilized laser fixed in the laboratory. It is thus possible to compare a length standard oriented in a variable direction with a similar but fixed length or time standard. Were space anisotropic, the rotating standard would vary as its direction in space was changed.

No effect was noted, and a new upper limit—4,000-fold improvement over the previous experiment—was set. Expressed in another (but equivalent) way, the results gave a null result of $\pm 2 \times 10^{-7}$ times the effect expected if there were an all-pervasive "ether" that carried light rays and the Earth were moving with respect to it (as was pictured in 19th-century physics).

This result is currently the most fundamental confirmation by direct measurement of Einstein's model of the space-time continuum as the "arena" in which physics takes place. Hall plans to continue his search for any small residual "preferred reference system" effects by another order-of-magnitude increase in sensitivity. Improved null results will further but-

test our basic theoretical view of the universe, while any positive result would require a rethinking of this view. In addition, the technical improvements made during this work make it possible to test other critical assumptions in physics with much improved sensitivity, such as the frequency shift of a moving atomic clock or the isotropy of the speed of light.

ment, and instrumentation into the industrial arena. The basic research training available in our universities has been shown over the years to be an excellent source of personnel to staff our industrial, governmental, and academic laboratories at all levels. The four topics which follow can scarcely do justice to the vitality of the discipline, but illustrate a few of the ways in which basic research in chemistry is solving both theoretical and practical problems.

Chemistry

Chemistry is enjoying one of the most exciting periods of its existence. The intractable problems of prior years are yielding to intense efforts built on advances in theory, experiment, and instrumentation. New molecules with preconceived structures and predictable physical properties are being produced. Further, the synthesis of new compounds, or of previously known compounds to which recently developed strategies have been applied, is imposing heavy demands on instrumentation designed to analyze the products of chemical reactions. In turn, the sophistication of modern instrumentation is posing a tremendous challenge to the chemist, for whom investigation of virtually every detail of composition, structure, and chemical dynamics is now possible. It is almost as if a magic eye is part of the arsenal of the chemist. Even the microscopic pathways of chemical reactions are now being unraveled by the chemist.

All of this progress would not be possible without advances in other disciplines such as quantum electronics, optics, computer science, and engineering. Yet the chemist stands alone as the architect of new molecular structures. When a chemical process is thoroughly understood, it is possible for the chemist to devise a number of alternative pathways to synthesize the end product. The successful design

of alternate synthetic methodologies is the most convincing argument that the original process proceeds in the manner deduced from prior experimental or theoretical evidence. The creation of new compounds further provides a powerful scientific method for the testing of hypotheses generated from allied theoretical or experimental results. The convergence of knowledge and hypotheses from many subdisciplines of chemistry, and from allied disciplines, is leading to significant advances in our understanding of the synthesis, structure, and function of molecules in a wide variety of living systems and industrial processes.

Basic human needs are continuously translated by chemists into research challenges; advances in chemistry provide a basis for social and economic improvement for all of mankind. Thus chemistry stands at a pivotal position among the many science and engineering disciplines, translating the results of curiosity-motivated research into solutions for problems in such diverse areas as pharmaceuticals, energy resources, synthetic fibers, and pest control. In effect, chemistry has become *the* interdisciplinary.

Additionally, the chemical industry in the United States is direct beneficiary of basic research at the universities, as a steady stream of young scientists, excited with new ideas, carry novel strategies in theory, exper-

"Snapshots" of Unstable Intermediates

Understanding the mechanisms of chemical reactions is one of the fundamental goals in chemistry and has many implications in other disciplines. Complex organic reactions frequently proceed through the intermediacy of elusive molecules whose high reactivity makes them exceedingly short lived.

Among the new spectroscopic techniques that have been invented for developing a "picture" of the structure of such very short-lived species are chemically induced dynamic nuclear polarization (CIDNP) and nuclear magnetic resonance (NMR) of photo-excited triplet states. In the former technique one takes advantage of the fact that certain reactions involving, among other things, the interaction of nuclear and electron spins, proceed through paramagnetic intermediates and are influenced by paramagnetic nuclei such as hydrogen-1, fluorine-19, or carbon-13. The time scale of the interaction between electron and nuclear spin is very short—on the order of one-billionth of a second; the information imprinted on nuclei by the spin interaction persists for seconds, as either emission or enhanced absorption in the NMR spectrum of the products, and can be extracted by the CIDNP technique. The technique has, to a large extent, been developed by G. L. Closs of the University of Chicago; it



CIDNP and NMR. Gerhard Closs and his colleagues at the University of Chicago are using new spectrographic techniques to study electron transfer in excited states. This phenomenon is central to photosynthesis and could, if better understood, be a possible source of chemical energy.

has proven to be an extremely versatile tool in the study of radical and photochemical reactions.

The study of photoexcited triplet states by NMR is also based on the interaction of nuclear and electron spins. In this case, the information is contained in the shape of the NMR lines for the molecules undergoing photoexcitation. From an analysis of the line shapes, it is possible to deduce the electronic structure of the triplet state molecule.

In addition, extensive use has been made of matrix isolation, in which a reactive intermediate is created at very low temperature (4.2 degrees K) via a photochemical reaction in an inert matrix. Since the molecule has no partner with which to react, it will persist and can be studied by conven-

tional spectroscopy such as electron spin resonance or infrared or Raman spectroscopy. Thus, structural information can be obtained using techniques usually applied to conventional, stable molecules.

Among the reactions studied by these techniques are transformations involving carbenes, radicals, biradicals, and radical ions produced by charge transfer processes. All of these highly reactive species are paramagnetic and lend themselves to investigation by magnetic resonance methods. Especially successful have been studies on biradicals, intermediates thought to be involved in many reactions. Although their existence had been postulated for a long time, their high reactivity made them very elusive.

Another series of reactions investi-

gated involves electron transfer in excited states. This electron transfer has to occur within the very short lifetime of the excited state. Once the electron transfer has taken place two radical ions are formed, which can be detected by CIDNP or other paramagnetic resonance techniques. If these ions could be separated, they would be a source of chemical energy in the form of oxidizing and reducing potentials which could be used to form new chemical bonds. This process takes place during photosynthesis in green plants and bacteria in which light energy is converted to chemical energy by a charge transfer mechanism. The resulting oxidizing and reducing substances are kept apart, so that the reverse reaction does not occur. Using the techniques described above, Closs and his research group are trying to gain an understanding of what might prevent the back reaction in vitro. Their research has involved photosynthetic pigments as well as some specially synthesized model compounds closely related to the photosynthetic reaction center in green plants. New insight has been gained, and this difficult problem is being pursued vigorously at the present time.

Metal Ions and Proteins Shape Biological Processes

"Bioinorganic chemistry," the study of metals in biological systems, is a rapidly growing research activity. Nearly a third of all enzymes require a metal ion for their function, and studies of "biological" metals will increase our understanding of the biological role of both common inorganic elements such as calcium, sodium, and iron, as well as biologically necessary trace elements such as chromium, molybdenum, and selenium. From a study of such systems we will also learn to mimic enzymatic reactions, such as the highly selective oxidation of hydrocarbons, which could have important industrial applications.

Specific proteins modify the chemi-

cal and physical properties of a metal in ways that often have no counterparts among simple chemical systems; the effort to understand the modification of a biological metal by its protein is a recurring theme of bioinorganic research. One strategy for studying this question is to prepare simple analogs of a metallo-protein active site. Comparison of structural, physical, and chemical properties of such analogs to those properties of "biological metal" may reveal the manner by which the protein affects the metal site. This research involves the design, synthesis, and isolation of a synthetic analog whose properties mimic the active pro-

tein site in the absence of the natural protein.

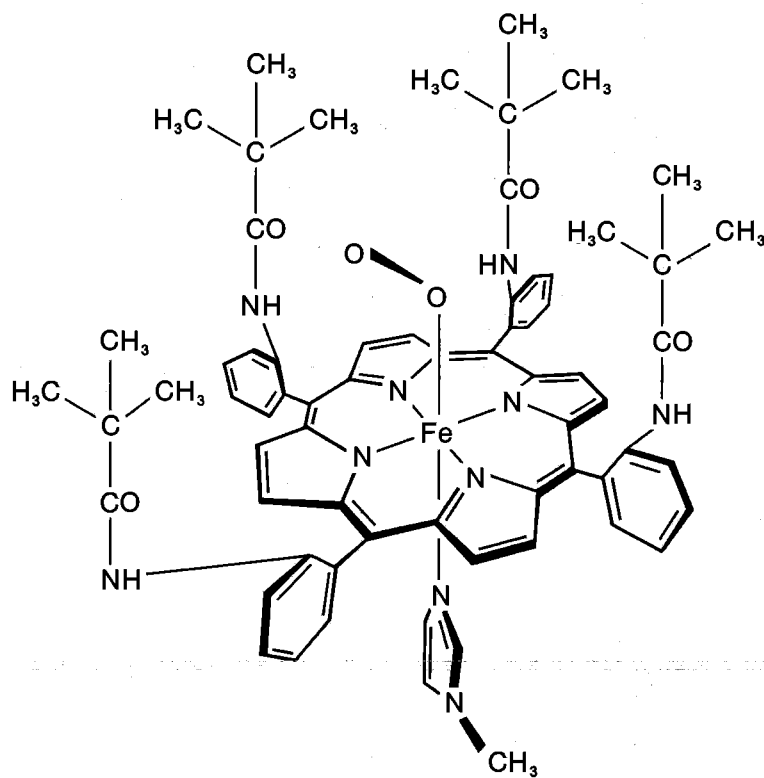
Recently, James Collman's research group at Stanford University and a number of other investigators, including T. G. Taylor of the University of California, San Diego, J. E. Baldwin of the Massachusetts Institute of Technology, C. K. Chang of Michigan State University, and D. H. Busch of Ohio State University, have prepared and characterized synthetic analogs of the active site in the oxygen-carrying hemoproteins, hemoglobin and myoglobin. These investigators have compared the structure and diverse spectral properties of these synthetic

"model compounds" with those of the naturally occurring hemoproteins. With proper treatment, for instance, iron porphyrin can become such an analog.

Both hemoglobin (the oxygen-carrying, red pigment in blood) and the closely related myoglobin (which gives beefsteak its red color and serves to store oxygen in muscle tissue) bind oxygen "reversibly." That is, there is no net change in these hemoproteins when oxygen is subsequently removed. Oxygenated heme complexes are unstable and should decompose by reducing the oxygen molecule to water and oxidizing (rusting) the iron atom. They do not.

Simple iron-porphyrin compounds, however, do decompose rapidly in air. But by chemically constructing a protective enclosure (a "picket fence") on one side of an iron porphyrin, this decomposition is prevented, so that crystalline iron-oxygen complexes can be isolated and their structures studied using X-rays. A large number of physical-chemical measurements, drawn from infrared, Raman, magnetic circular dichroism, nuclear magnetic resonance, and Mossbauer spectra, for example, show that these synthetic analogs are remarkably similar to oxygenated hemoglobin and myoglobin.

The oxygen affinity of natural myoglobin is quantitatively mimicked by the "picket fence porphyrins." Hemoglobin's attraction for oxygen is more complex. In the lungs, hemoglobin binds oxygen strongly. But at the lower oxygen concentration found in tissue, hemoglobin binds oxygen less strongly, permitting complete transfer of oxygen from hemoglobin in the blood to myoglobin for storage and use in the tissue. To accomplish this transfer, the affinity of the hemoglobin tetramer (four-unit polymer) dramatically decreases as two of its subunits release oxygen. This strange property, called "hemoglobin cooperativity," is essential to hemoglobin's physiological function. The Stanford



A mimic for hemoglobin. This synthetic chemical is known as a "picket fence" dioxygen complex because an "enclosure" bordering an iron-porphyrin group prevents it from decomposing in the presence of air. In this way the simple compound acts like the biologically important heme complexes and can be used for study of how proteins and metals interact in living systems.

group has shown that the iron's oxygen affinity is exquisitely sensitive to the position of an imidazole group—quantitatively supporting a previous observation by Nobelist Max F. Perutz of Cambridge University. X-ray analysis at Northwestern University reveals the structural effects of stress induced in this low affinity iron-oxygen complex. The Stanford chemists have also discovered a solid "picket fence" complex that binds oxygen cooperatively in a manner remarkably similar to hemoglobin. It is hoped that a structural analysis of this cooperative synthetic analog may further clarify hemoglobin cooperativity.

Finally, it has been observed that the synthetic "picket fence porphyrins" bind carbon monoxide much more strongly than do hemoglobin and myoglobin. This observation has led to the suggestion that amino acid groups near the carbon monoxide lower their affinity by "tilting" the CO group away from its "natural" geometry, while not affecting the oxygen, which is normally bent. Thus, nature has carefully shaped the oxygen-binding protein cavity to maximize oxygen affinity while minimizing the attraction for poisonous carbon monoxide. Carbon monoxide is not only a modern pollutant (cigarette smoke, auto exhaust, charcoal fires) but also occurs naturally when an organism discards worn out heme groups. A prediction from this hypothesis has recently been verified in Cambridge by a study of hemoglobin mutants lacking one of the interfering amino acid groups. Thus far the "tilted CO" group has not been modeled.

Research of this sort requires numerous collaborative interactions between many kinds of scientists and cuts across traditional subdivisions (i.e., inorganic, organic, and physical chemistry) as well as wider areas of science (i.e., chemistry and physiology). As modern science becomes increasingly complex, such collaboration between diverse scientists will become ever more necessary.

Light Scattering: Shape and Movement of Large Molecules

It has long been known that irregularities, or inhomogeneities, in an otherwise uniform medium can scatter light. That is, they can change the direction of propagation of light traveling through the medium. For example, this is the reason that the sky is blue. The scattering ability of the atmosphere depends on the wavelength of the light, and blue light is scattered more strongly than red. The red portion of sunlight comes to us more or less directly, in a straight line from the Sun. If it were not for this scattering, the sky would be black, except near the Sun. This explanation was made quantitative by the British scientist, Lord Rayleigh, in the 19th century.

Scientists have developed the technique of light scattering to study the size and shape of macromolecules in solution, of inhomogeneities in the atmosphere, and a host of other problems. In the past decade a revolution has occurred in the field as a result of the laser, which is a very intense and spectrally pure light source.

Light scattering is generally a weak process, so that an intense source, a long measurement time, or very sensitive detection is needed. The high intensity of a laser source enabled scientists to make normal light-scattering measurements much more accurately and conveniently than previously. In fact, lasers have almost completely replaced conventional light sources for scattering experiments, and the spectral purity of laser sources enables a completely new kind of scattering experiment to be performed: inelastic scattering, which arises because the light wave can actually exchange small amounts of energy with the scattering medium. Measurement of the intensity of the scattered light as a function of the shift in wavelength can be analyzed to give important information about the details of molecular motions in fluids.

While light scattering is usually a weak process, the critical region provides an important exception. The critical region of a fluid is the range of temperatures and pressures at which the liquid and gas phases are losing their identities, becoming indistinguishable. Experimentally, this region is characterized by very strong light scattering. In fact, fluids in their critical region are opalescent, or milky looking. Careful light-scattering measurements have yielded much information on structure and dynamics in this region of temperature and pressure.

An interesting example comes from the work of George Benedek, a pioneer in this area, and his group at the Massachusetts Institute of Technology. These workers are using the light-scattering technique to study mixed micelles of bile salts, lecithin, and cholesterol. Micelles are small colloidal aggregates that form in certain solutions when the concentration of solute is increased. These particular micellar solutions are of special interest because the materials are found in bile. Benedek and his group have measured the size and shape of these micelles as a function of the particular bile salt. An exciting aspect has been the study of the rate of cholesterol microcrystal formation from supersaturated solution. These microcrystals may be viewed as incipient gallstones, so the physiological interest is clear.

A second example is from the work of the group of Robert Pecora at Stanford University. This research group is using light scattering to study the rotational motion of small molecules, both in the pure liquid and in solution. An interesting result of these studies is that the mean rotational dynamics of small molecules in solvents whose molecules are nearly spherical appears to be successfully predicted by a version of classical hydrodynamics. This is a surprising result, since hydrodynamics is a theory developed to apply to objects much larger than the solvent molecules. In fact, the experiments show that the theory also ap-

plies to molecules of the same size as those of the solvent. The reason for this is not understood, and a number of theoreticians are trying to understand why it happens. The experimental light-scattering work gives direct verification of the existence of the phenomenon.

As technique develops and instrumentation improves we expect to see more and more new information and new insights revealed by light-scattering studies. Then we can probe more deeply into the detailed dynamics of molecules in condensed phases.

The Border Between Two States of Matter

In the past two decades there have been remarkable advances in our understanding of phase transitions: processes such as the condensation of a vapor to a liquid, the separation of a previously homogeneous solution into two distinct liquid phases on cooling, or the spontaneous magnetization of a magnetic material. Commonly, phases coexist in equilibrium, when the transition between them is arrested while some of both are present; for example, a liquid may be in equilibrium with its vapor in a closed container, or a magnetic solid may be made up of domains of opposite magnetization. It is the interface between two such separately homogeneous phases in equilibrium that is the subject of study by the research group of Ben Widom at Cornell University.

The interface between a liquid and its equilibrium vapor is often referred to as "the surface of the liquid," but it is just as well a bounding surface of the vapor; an interface belongs equally to the two phases that it separates. Ordinarily an interface is very thin. We go from the interior of one of the bulk phases to that of the other over a distance of just two or three molecular diameters. But that is only so when the two phases are very distinct; when, by contrast, the two phases are

very similar—near the critical point of the phase equilibrium—the thickness of the interface can approach the wavelength of visible light (about 1,000 molecular diameters).

Interfacial thicknesses have most commonly been measured by the technique of ellipsometry—measuring the ellipticity of light reflected from an interface. A long-sought goal has been to determine the detailed spatial variation of composition as one goes from one phase, through the interface, to the other phase.

The interface is necessarily the seat of inhomogeneity between the two otherwise homogeneous phases it separates. The excess free energy due to that inhomogeneity is called the interfacial tension, and manifests itself as a force that resists increases in the area of the interface. (When one of the phases is a vapor, that tension is often called the "surface" tension of the liquid or solid with which the vapor is in equilibrium.) It is the most readily measurable property of an interface, and also the one of greatest practical importance.

The Cornell group is concerned with the relationship between the tension of an interface and its structure. Their recent work has been directed to three-phase equilibrium with three different interfaces. Examples of practical importance occur when the three phases are oil, water, and surfactant, as in tertiary oil recovery, where knowledge of the three interfacial tensions is cru-

cial. The systems studied by the Cornell group are, in principle, similar to the oil-water-surfactant systems, but are more amenable to quantitative study and are thus better testing grounds for theory.

Just as ordinary two-phase equilibrium terminates at a critical point where the two phases become identical, so three-phase equilibrium terminates at a tricritical point. At any temperature, the range of composition in which three phases coexist is bounded by two critical end points (each the critical point for the equilibrium of one pair of the phases), which approach each other as the temperature approaches the tricritical point. The Cornell group studied the three interfacial tensions from critical end point to critical end point. The variation of the tensions between the two critical end points is in accord with theory. One of the three tensions vanishes at each critical end point, and near that point is the range of "ultra-low" tensions that is of practical importance in surfactant technology. The Cornell group established that, whatever their separate values, the largest tension is always the sum of the two smaller, and predicted theoretically that the interface of highest tension has a structure nearly identical to that of the bulk third phase. In a collaboration with W. W. Webb of Cornell, Widom's group is now testing that conclusion by ellipsometric studies of that unique interface.

Mathematical Sciences

Mathematics originated in humanity's early attempts to master problems of commerce and agriculture. From that time, it has continued to play an important role in our culture and has in turn been constantly enriched by it. In particular, it has played an essential role in the development of the

physical sciences and technology, and these in turn have been the wellspring of much mathematics. Thus, there has developed on the one hand a discipline of mathematics qua mathematics (or pure mathematics) and on the other hand the applied mathematical sciences, or the study of the applications of

mathematics to specific classes of problems. For either of these broad areas, mathematicians over the years have developed a variety of tools.

Mathematical analysis began with the invention of the calculus in the 17th century and continues to attract more mathematicians than any other single field. Some continue to work on classical problems with techniques that would not have surprised an 18th-century mathematician; others bring to bear tools from modern algebra and topology. Geometry runs the gamut from differential geometry, which has applications in relativity theory and general field theory, to the study of planes having only finite numbers of points (which has, among other applications, relevance to the design of magnetic core memories for computers). The field of foundations comprises mathematical logic, with obvious relevance to computing machines, and the axiomatic theory of sets, the apparent paradoxes of which have stimulated some of the finest mathematics of the 20th century. Algebra and topology are inextricably mixed; tools from each have been applied in the other, and the quest for further tools has then inspired substantial advances in the field being applied. Modern algebra is concerned with the study of mathematical structures such as groups, modules, and rings. These structures, and techniques involved in their study, are used to provide insight into other areas of mathematics such as algebraic geometry, theory of vector spaces, and number theory. Topology is, so to speak, a refined kind of geometry that is concerned with geometric properties that do not depend on distance or angle.

One of the great themes of mathematics today is the growing synthesis of its parts. Insights from harmonic analysis turn out to be useful in combinatorics, methods from topology are needed in solving problems in differential equations, and number theory requires methods from analysis and to-

pology. There can be no doubt that this great movement will continue as mathematics continues its search for form and pattern.

A second major theme now slowly emerging, and perhaps also destined to become one of mathematics' major developments, is the use of the computer in mathematical research. It serves as a tool for testing conjectures, it suggests mathematical problems, and it has highlighted the concept of algorithm in the solution of problems.

Applied Mathematics

The development of complex spatial patterns in fluids capable of both reacting and diffusing has interested scientists since Alan Turing demonstrated the role this phenomenon may play in morphogenesis. Recently, much attention has focused on a particular chemical reaction, the bromination of malonic acid in the presence of cerium-four ions. This reaction, identified with the names B. P. Belousov, P. N. Zaikin, and A. M. Zhabotinskii, all of the U.S.S.R., has many intriguing experimental features. Certain homogeneous, well stirred preparations of the BZZ reagent function as a chemical oscillator. These same preparations, when placed in a thin petri dish, tend to organize themselves into stable target-like and rotating spiral patterns that oscillate indefinitely. Experiments with these reactions have been described by chemist Arthur Winfree of Purdue University, who has served as a real catalyst to applied mathematicians interested in such problems.

Over the past several years NSF's applied mathematics program has underwritten much of the significant mathematical research done in this area of reaction-diffusion systems. Grantees working on such problems have included J. F. C. Auchmuty, Indiana University; John Evans, University of California, San Diego; Paul Fife, University of Arizona; D. G. Aronson and Hans Weinberger, University of

Minnesota; Donald Cohen and Paco Lagerstrom, Caltech; J. M. Greenberg and Stuart Hastings, State University of New York, Buffalo; Nancy Kopell, Northeastern University; and L. N. Howard, MIT.

Much of the mathematical work in this subject has dealt with hypothetical systems that exhibit spontaneous, self-excited, spatially homogeneous oscillations. Investigators have succeeded in demonstrating that such systems support spatially inhomogeneous solutions that exhibit the target patterns and rotating spiral waves observed in the laboratory experiments.

Also of interest was whether such patterns could be sustained in excitable media such as nerve tissue or some preparations of the BZZ reagent. Such media have the property that, in a spatially homogeneous or well stirred process, they always return to equilibrium. It has recently been shown that such systems support rotating spiral waves and that such waves will emerge if sufficiently large inhomogeneities (concentration gradients) are present initially. An interesting feature of this analysis was the interplay of the diffusive and kinetic mechanisms of the system. For excitable media, the diffusive terms (typically a dissipative mechanism) act as a destabilizing influence for points close to equilibrium, and it is this fact that allows the spiral patterns to emerge and persist.

Interest in spiral structures of a completely different kind has been the focal point of other projects in applied mathematics. C. C. Lin and Alan Toomre of MIT have been working on basic mechanisms for maintaining spiral structures in galaxies. This project has sought to bridge the gap between what is called the WKB and global-mode approaches in the study of spiral density waves in galaxies. Some specific and easily understood full-scale modes in a large and plausible class of disk galaxies are now predictable as a result of their work.

Quillen on the Serre Conjecture

In 1955, the noted French mathematician J. P. Serre posed an important problem that has had considerable influence on the development of the field of commutative algebra in the past 20 years. The problem, generally referred to as Serre's Conjecture, can be stated in the following manner: if f_1, f_2, \dots, f_r and g_1, g_2, \dots, g_r are polynomials in n variables such that $f_1g_1 + f_2g_2 + \dots + f_rg_r = 1$, then there is an $r \times r$ matrix of polynomials with first row (f_1, f_2, \dots, f_r) and determinant 1. This problem, though mathematically simple and straightforward in appearance, proves to have very important consequences, particularly in algebraic geometry.

Many contributions to the solution of the problem have been made. A few of the more significant historical developments include:

- In 1958, C. S. Seshadri, an Indian mathematician in Paris, proved the result for $n = 2$.
- In 1960, Serre himself showed that the validity of the problem for $n = 3$ had an extremely important consequence in algebraic geometry (i.e., that every curve of genus 0 or 1 is a complete intersection).
- In 1964, Hyman Bass of Columbia University showed the conjecture to be true whenever $r > n$.
- In 1973, following a period of intense activity, three young Soviet mathematicians, A. A. Roitman, V. N. Suslin, and L. N. Vaserstein contributed significantly to important extensions, including the cases $n \leq 4$. Some of this work extends independent joint work of

M. P. Murthy and Jacob Towber, at the University of Chicago and DePaul University, respectively.

- Finally, in February 1976, the problem was solved completely by Daniel Quillen of MIT, using many ingenious ideas and some deep results of algebraic geometry. It was for this, and other work in a wide variety of important areas of algebra and algebraic topology, that Quillen was awarded the prestigious Fields Medal by the International Congress of Mathematicians in 1978.

Quillen's research was partially supported by an NSF grant; in addition, Bass, Murthy, and Towber are currently receiving support under NSF grants, and Serre and Seshadri have occasionally received NSF support for visits of extended duration to U.S. institutions.

James-Stein Estimation

A result in the abstract theory of estimation, which was originally viewed by many as a mathematical curiosity, has recently been refined and expanded so that it is beginning to have a great impact on the way applied statistics is done.

Estimation theory is one of the oldest branches of mathematical statistics. In recent decades some aspects of estimation have been studied in the framework of decision theory, in which it is assumed that the loss that is suffered from making an incorrect estimate can be stated in monetary terms. With the most common loss function, "squared error loss," the loss is proportional to the square of the difference between the estimate (based on data) and the

true value of the parameter being estimated.

Since this true value will be unknown in practice, theoreticians often work in terms of "risk," the loss averaged over all possible situations. Some "estimators"—formulas for computing an estimate from data—give a smaller risk than others. The smaller the risk, the better the estimator.

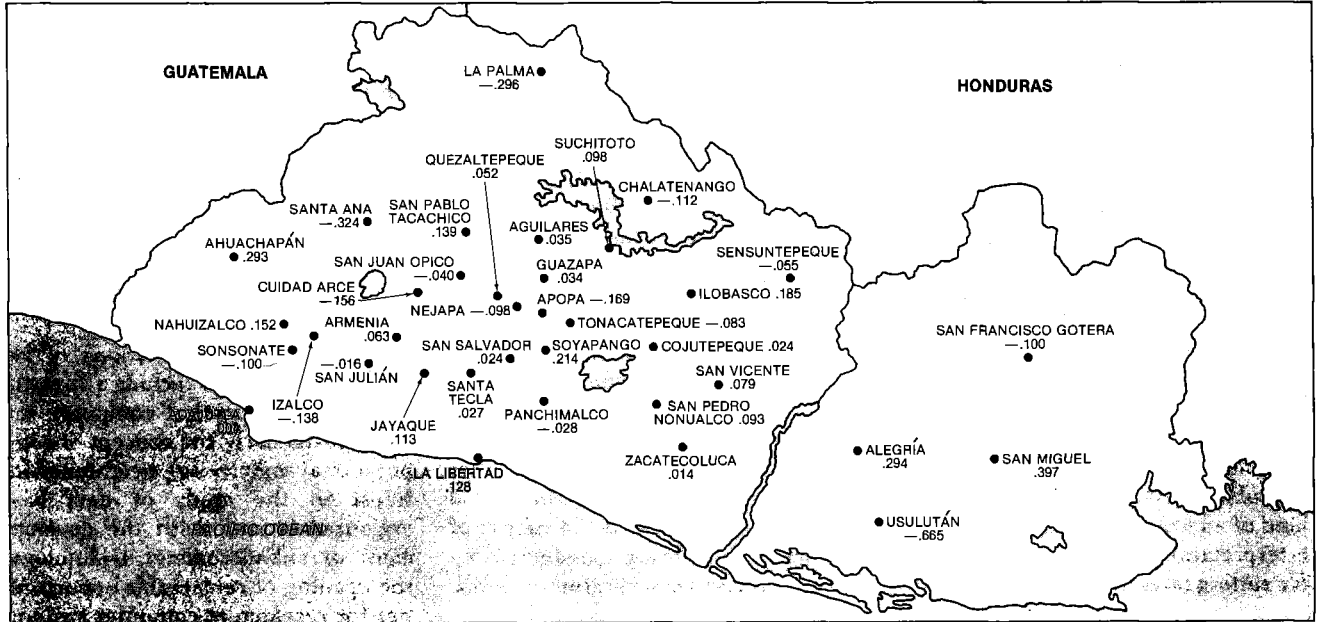
If the problem is multivariate, involving the estimation of many parameters, the risk takes into account each of the appropriate contributions, but for the result to make sense in practice all of the components of loss have to be "paid out of the same pocket." For example, if the problem involves one person investing in stocks on several exchanges, one company insuring automobiles in several towns, or one agency trying to assess pollution nationwide, this combining of risks makes sense. In an example involving financially unrelated components the combined risk would be difficult to interpret.

In many common situations the sample mean (simple average of the data) is the best estimator of the mean of the population from which the data were taken. If two population means are to be estimated, the best procedure is to compute the sample means separately as estimates of their respective population means. If three or more populations are involved, the same procedure could, of course, be followed. But the surprise is that in estimating three or more population means this straightforward procedure is no longer best. The combined risk is reduced, often greatly, by using a more complicated estimator for each population mean. This involves not only the mean of the data directly pertinent, but

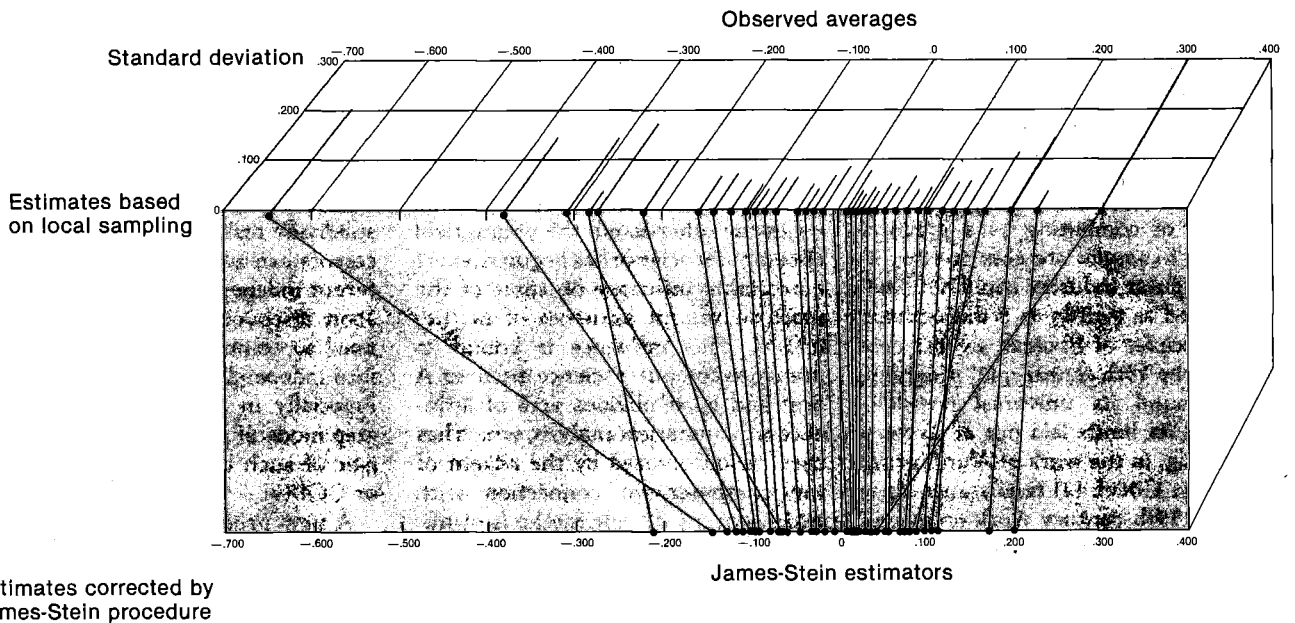
Disease distribution. As reported in the May 1977 *Scientific American*, measurements of the incidence of blood disease in 36 El Salvadorean cities showed individual city rates ranging from 65 percent below the national average to 30 percent above. However, treatment of the data by the method of James-Stein estimation, which considers the uncertainty associated with each city's measurement and the overall pattern of the measurements, alters the estimate of true disease prevalent in each city. James-Stein estimators are now finding use in many fields, including public health and insurance. (From "Stein's Paradox in Statistics" by Bradley Efron and Carl Morris. Copyright© May 1977 by Scientific American, Inc. All rights reserved)

Local Deviations from the El Salvador National Average in the Incidence of the Disease Toxoplasmosis

Geographic Distribution of Samples



Corrections to Estimates



also data relating to all the other populations.

The existence of such improved estimators was anticipated in papers published by Herbert Robbins of Columbia University in 1952 and Charles Stein of Stanford University in 1956. In 1961, Wallace James and Stein (both at Stanford) gave an explicit formula.

Acceptance of James-Stein estimators might have been more rapid if it had been more widely known that researchers in at least two applied fields had already proposed procedures somewhat like them, based strictly on empirical grounds. As early as 50 years ago psychologists had discovered they could get a more useful profile of parameter estimates for a whole group of subjects by a complicated scaling of high test scores downward and low test scores upward, even though this may distort estimates for some individual subjects. And in the 1950's a similar kind of ad hoc scaling turned up in the interpretation of insurance claims data for setting rates in a complex of market

areas. In both cases the complicated scaling formulas seemed artificial at the time because of the lack of theoretical justification. In retrospect, the formulas derived empirically in these two cases are seen to be very close to the James-Stein formulas.

In recent years the ideas in the James-Stein-type estimators are used to a vast variety of situations and to the estimation of parameters other than population means. Spectacular improvements in the accuracy of estimation are often achieved when the James-Stein type estimators are used in place of traditional ones. A few of the many areas of successful application of this now burgeoning area of new statistical methodology are analysis of public health, insurance, energy resources, and accident data. The development of methods that will allow application of these ideas to other areas, including inventory control and experimental physics, is the subject of research now being conducted by mathematicians in several institutions.

long ago by Isaac Newton, Karl Friedrich Gauss, and Adrien Legendre and use methods that were easily accessible to these great classical figures. Further, combinatorics has been affected just as much, and the computer influence here has been strengthened by the fact that many of the central algorithm design and analysis problems of computer science are combinatorial in nature. Thirdly, the possibility of performing extensive symbolic computations by computer has revived the study of constructive methods in algebra and deepened understanding of techniques for carrying out even such classical processes as polynomial factorization.

With respect to directions of research, clear trends include a surge of activity in theoretical computer science (particularly the concept of computational complexity), heightened interest in the study of data base organization and, with the development of submicrometer technology, the opening of remarkable opportunities for research in computer systems ranging from theoretical study of complexity and the logic of computing systems to design issues and applications.

Computer Science

Computer science has drawn many of its most fundamental concepts from mathematics. As pointed out recently in the writings of Jacob Schwartz of New York University, this heritage of ideas has accelerated greatly the development of computing as a practical activity. Examples are easy to cite: (1) the computer industry could not have developed as swiftly as it did without the principles of Boolean algebra created in the 19th century; (2) programming found its universal possibilities and its limits laid out at its very beginning, in the work of Alan Turing and Kurt Gödel; (3) renaissance algebra and 19th-century work on matrix algebra contributed essential concepts and notations to the development of the computer languages FORTRAN

and APL; and (4) notions and techniques drawn from matrix theory have been absorbed wholesale by computer science and have been fundamental to the design of many high efficiency algorithms.

On the other hand, the young field of computer science has begun to exert a profound influence on some of the most significant branches of mathematics. This influence is bound to deepen as computer science matures. A first and most obvious area of influence is in numerical analysis, which has been revolutionized by the advent of the computer, in connection with which dozens of new methods of numerical calculation have been developed. Surprisingly, some of these new methods relate to areas worked over

Applicative Programming

Semiconductor technology has made the processor and memory components of computers cheap. To take advantage of this technology in order to increase speed, it is natural to try to subdivide tasks so that different processors can act simultaneously on different independent subtasks. But it is soon discovered that many subtasks need to communicate; decomposition into independent subtasks is not easy, especially in the traditional step-by-step mode of programming characteristic of such languages as FORTRAN or COBOL.

A new programming style, applicative programming, is closely related to conventional mathematical practice, which is free from this cross-com-

munication problem. In mathematics, a function is an operator that creates a correspondence between a set of arguments and a set of function values. The function is said to be "applied" to its arguments to determine its values. The value obtained in any evaluation depends only upon the definition of the function and the specific choice of arguments, not upon the environment in which the evaluation is performed. The evaluation may be made anytime the proper choice is known, and the value can be saved until needed or the evaluation may be postponed until the value is needed.

In programming, algorithms play a role analogous to functions in mathematics. The applicative style of programming takes advantage of that analogy to make the intrinsic independence of various parts of a calculation apparent. As a result, applicative programming languages have considerable potential for expressing parallel processes using multiple processors. For example, Daniel Friedman and David Wise of Indiana University recently have obtained insights relating program structure and data structure. In their work, a set of values (even infinitely many) can be specified by an expression telling how to evaluate any element, but the evaluation can be suspended until particular elements are needed for a subsequent calculation. The system itself should have the responsibility of anticipating where values will be needed and of scheduling processors to provide values on schedule. The programmer should not need to be concerned with such issues. Different strategies might be used, depending on the availability of processors and the advantage of preevaluation as compared to the possible cost of generating values that will not actually be needed.

Programming languages can be viewed as models of the computers for which they are used to express programs. Traditional languages, such as COBOL or FORTRAN, are models of the traditional single-processor/single-

time-stream computer. Applicative languages should be models of computers having a different organization (presumably multiple-processor) and responding to primitive operations quite different from those in traditional computers. Gyula Magó at the University of North Carolina is searching for such organizations and for effective primitive operations. For example, the fact that the main memory of an applicative computer is not addressed in the traditional way leads to a need for operations to structure and restructure data for efficient access. Also, the natural parallelism of these languages often requires the same program to be applied to many distinct data sets or requires that different programs be applied to the same data set. In either case, multiple copies of expressions are produced requiring operations to distribute the expressions appropriately through the system.

Applicative languages and corresponding computers are far from commercial use. Commercial organizations can rarely afford to pursue such ideas. Yet, efficient use of processor parallelism may be the final resort for increased speed when the limits imposed by the laws of physics are approached in device and circuit design. One can expect the theories of applicative programming to influence the architecture of future generations of computers, since these theories offer a useful programming style for a processor-rich computing environment.

Computer Conferencing

Timely communication among scientific researchers is becoming increasingly difficult. An article may take a year or more, from the time it is submitted, to appear in a journal. Researchers in the same field may be widely scattered, and travel funds are limited. Some computer scientists are exploring the use of the computer to augment communication, while reduc-

ing the time and expense of travel, through a new technology called "computer-based-conferencing," (CBC).

In a CBC system, the computer is the center of a communication network. It provides facilities for storing and forwarding messages between scientists, for structuring conferences among groups of scientists, for providing computerized "notebooks" in which users can develop joint papers and monographs, and for making available public "bulletin boards" for general announcements and comments of interest to all members of a network. By providing such information-handling services, the computer can mediate a long-term, continuous discussion among researchers. Participating scientists enter the system at their convenience, read their "mail," send any comments they might have and, perhaps, peruse the bulletin board for any new items of interest. The system keeps track of what they have or have not seen and stores complete transcript. Past items can be recalled by a variety of searches based on date, content, topic, or other facts any user might remember about the message.

Researchers at the New Jersey Institute of Technology and at the Institute for the Future (IFF) in Menlo Park, Calif., have been studying the design and structure of CBC systems, as well as investigating their impact on scientific users. The IFF group is particularly interested in CBC as a way to engage dispersed interdisciplinary groups in the construction and validation of large-scale computer models. The New Jersey group is looking at languages for the design and structuring of specialized CBC systems tailored to achieve specific goals among scientific groups. These goals may take such forms as setting research agendas, testing computer programs, or evaluating scientific reports. Much needs to be discovered not only about the basic design of messaging systems but also about changes in the behavior of their users.

The experimental success of the pro-

jects so far in deriving useful communications systems for scientists has led to the formation of Theorynet, a group of computer science theoreticians linked with one another over a CBC

system based at the University of Wisconsin. The experience of this group may well lead to the formation of even more extensive communication experiments among computer scientists.

Engineering

NSF's engineering program supports basic research with the purpose of adding new knowledge of engineering principles and physical phenomena important to the solution of technological problems. The research is basic in the sense that the search is for theoretical and experimental knowledge applicable to large or general classes of problems and useful over a relatively long timespan. Although engineering investigators are ordinarily driven by a perceived application of their research, often entirely unexpected applications result from this type of basic research.

The performers of this research are concentrated among the 14,000 members of engineering faculties in the 773 doctorate-granting university engineering departments. Additionally, research is being encouraged by special programs in industry under which both direct support and support for collaborative university-industry efforts are provided.

In order to respond to the huge diversity of topics and areas represented by basic engineering research, NSF's engineering programs are organized into 13 areas grouped into three sections. Research is supported in four major disciplinary areas (civil, mechanical, electrical, and chemical engineering), as well as in a score of other related disciplines. Interdisciplinary efforts are encouraged,

In engineering mechanics, the groundwork has been laid for the development of a very large geotechnical centrifuge to be used in the verification of analytical predictions of the behavior of earth and earth-structure systems under a variety of static and

dynamic load conditions. Topical areas to benefit from this new experimental approach include dam safety, earthquake engineering, mining and drilling operations, and in situ energy recovery systems. In fluid mechanics, significant progress has been made toward the understanding of the structure of turbulence. In particular, the vortex structure within a turbulent spot has been resolved using laser-Doppler techniques. Also, new models of the slow, viscous-dominated motion of micro-organisms have been developed. In solid mechanics, further studies on the fracture of materials are being undertaken, with emphasis placed on fast fracture, plastic-crack propagation, and propagation of parallel cracks in hot, dry rock. These phenomena are particularly important in the design of pressurized pipelines and geothermal energy-extraction systems. Also, two recent workshops have identified the importance of research in robotic manipulators, and investigators in mechanical sciences are now directing some of their efforts to this important problem. Also continuing are fundamental studies in erosion and transport of sediment; diffusion, dispersion, and biological interaction of pollutants; hydrology and water resources; flow in underground aquifers; and experimental acoustics. Two recent workshops have identified research needs in water and waste water treatment systems and also in conducting large-scale field experiments in environmental engineering. Studies in these areas have been initiated at a modest level and are expected to increase in the future.

Research in engineering chemistry

and energetics has provided new techniques for fabricating membranes and characterizing catalysts. It has also led to fundamental understanding that will aid in the a priori design of membranes and catalysts to accomplish specific tasks, including catalysts impregnated on membranes to facilitate product separations. Basic studies on the kinetics and transport processes in biochemical systems have yielded results that will enhance our capability in using renewable resources. Recent advances in instrumentation have shed new light on the thermal convection mechanisms in various geometries relevant to fire detection, solar energy collection, thermal energy storage, and cooling of nuclear reactors. Intercollegiate cooperative research on neutron properties has resulted in procedures for benchmarking transport measurements and for analyzing geometrically complex neutron-radiation shielding problems. Development of rapid-response thermal, optical, and photoacoustic probes has been making significant contributions delineating the particle behavior in fluidized beds useful for coal combustion and gasification as well as food and ore processing.

In electrical sciences and analysis, research is progressing in a variety of areas. In submicron engineering, the pace of work is picking up at the National Research and Resource Facility for Submicron Structures, started in 1977 in cooperation with Cornell University. Workshops and open house sessions have acquainted the research communities with the facilities and services. This activity is important because of the economic importance of the semiconductor integrated circuits industry and also because of the additional opportunities foreseen in science and over a broad range of engineering. Related submicron research ranges over a wide variety of topics, such as inorganic resists for electronic device fabrication, molecular beam epitaxy for ternary semiconductor devices, studies of niobium Josephson junc-

tions, of submicron Josephson weak links, of phenomena in chemical sensors, of soft X-ray lasers, of transient spectroscopy of laser-annealed interfaces, of modeling and optimization in submicron device fabrication, and of surface acoustic waves and integrated optics devices. In the matter of inorganic resists, research results obtained to date are likely to have a large impact on circuit fabrication techniques. Similarly, if chemical sensors can be incorporated in actual microelectronic devices, remote sensing and environmental monitoring efforts will all benefit appreciably.

Other major efforts in electrical sciences and analysis span basic research in communications, automation, bioengineering, complex systems, and operations research. In all of these, a pervasive feature is the increasing use of computers and of other specialized digital system information processing structures for implementing the desired algorithms and functions.

Typically, some of the research results find direct application, such as providing an improved method for

carrying out automated counting of asbestos fibers in air or an improved method for obtaining estimates of geological reserves. Other research—such as in multiuser computer network communications, computer-aided design, production and test methodologies, complex systems, and control theory—is of fundamental nature and also of basic importance to the development of technology.

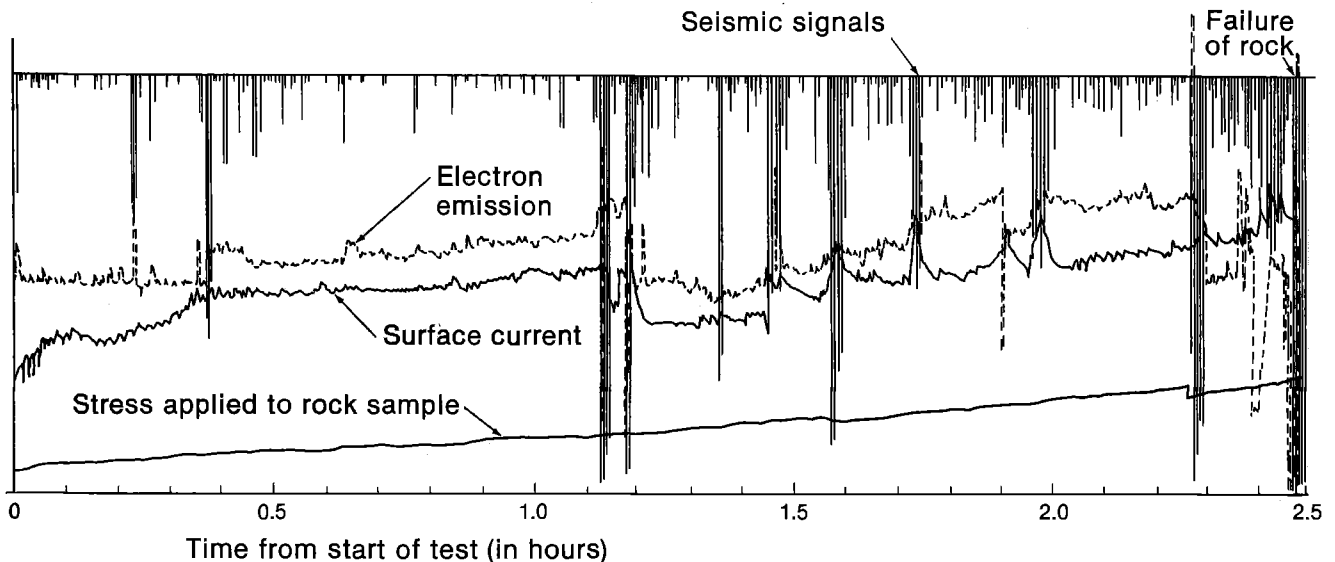
Prefracture Phenomena of Rock

Understanding how rock responds to stress in terms of the movement of absorbed water and ions from regions of compression to those of tension is the primary objective of a research project being carried out at the University of Arizona. Stuart A. Hoenig of the Department of Electrical Engineering is studying the electrical phenomena associated with stress in rock and ceramic materials; he theorizes that this electrical effect can be used to predict underground

rock bursts and, ultimately, earthquakes.

It has already been established that it is possible to make electrical contact to rocks and ceramics by a variety of techniques, from conductive epoxy to hammered-in phonograph needles. Electrical currents at the level of 10^{-11} ampere have been observed as the rocks are stressed; the resulting current patterns can be used to predict the location of ultimate failure. In some cases, it is possible to work with rock cores that have significant residual stress and to predict where failure would occur when the load is increased.

It has also been established that the signals are due to two phenomena. When the load is suddenly increased, there is the usual piezoelectric signal. This dies away due to leakage through the rock, but there is a residual, stress-related current which we associate with migration of absorbed water and sodium ions. This current is greatly increased when the rocks are saturated with water; at the same time, the piezoelectric current disappears.



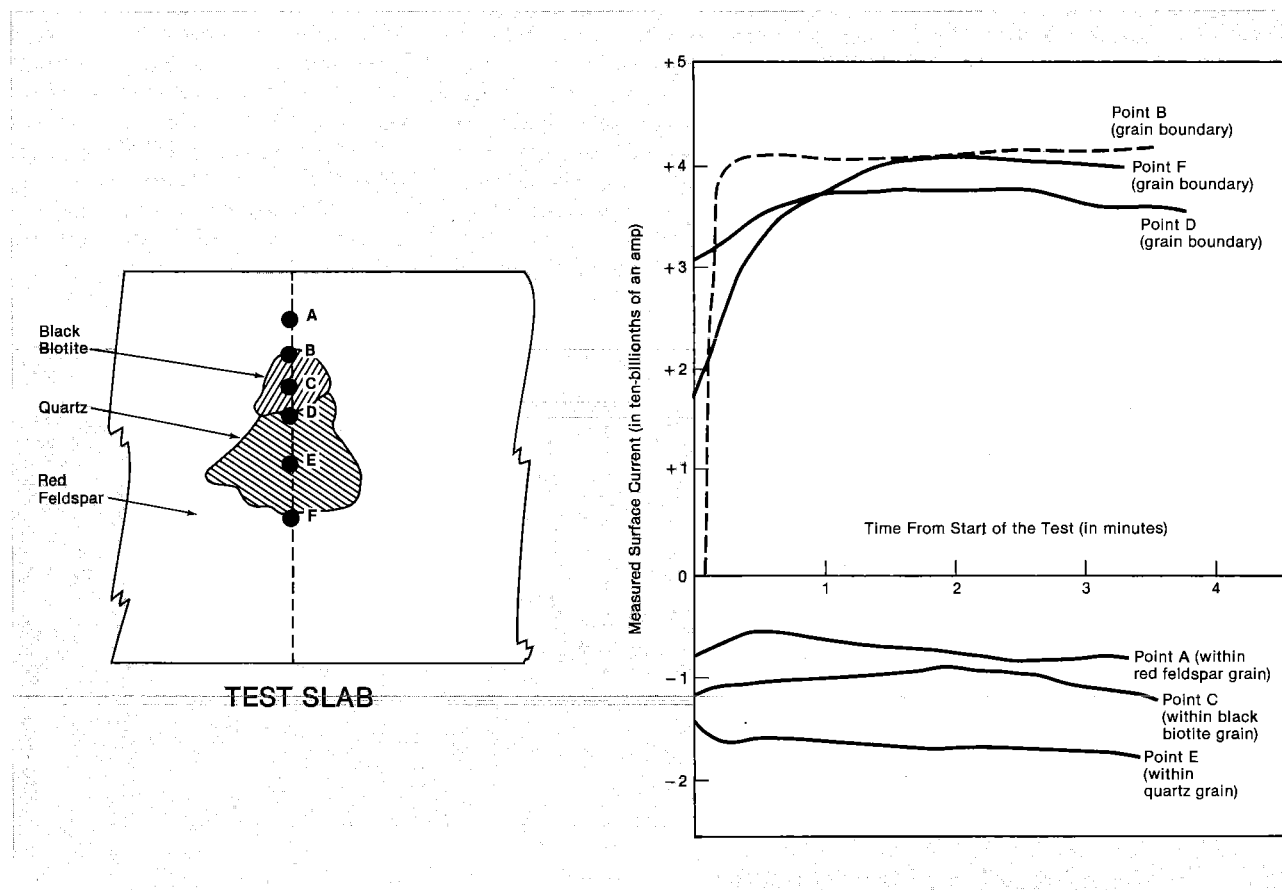
Simulating a rockburst. When stress is steadily applied to an instrumented rock sample, measurements of seismic data, surface electrical microcurrent, and electron emission current are closely correlated. The seismic signals are caused by micro-fracture and are predicted by an earlier jump in surface current. Warning devices that measure surface current rather than seismic signals may lead to greater safety for workers in mines.

In more recent studies, the effects of very slow increases in stress to simulate the situation that occurs before an earthquake or rock burst have been examined. Typical results have shown excellent correlation between the surface current, electron emission, and the seismic data. The periodic bursts in the seismic signal, generated by microfracture in the specimen, are matched by bursts of electron emission and jumps in surface current. Surges noted in surface current that occur just before fracture are of the type that have been observed in the seismic signals from a mine instrumented to predict rock bursts.

The most recent laboratory effort at the University of Arizona has been devoted to proving that the surface currents are indeed due to the stress-induced migration of water and associated ions. For this experiment, a rock slab is stressed and the current measured at grain boundaries and in the center of the grains, over an area of constant stress. It is clear from the experiments that the current at the grain boundaries is much higher than that from the crystals, as would be the case if diffusion were taking place. It is felt that this is at least a partial verification of the stress-induced migration theory.

Microscopes for Microstructure

New techniques with microscopes exploiting many wavelengths of radiation beyond normally visible light have been opening window after window on the microworld. The objective of research being conducted by Robert W. Hellwarth at the University of Southern California is to open a window to exploit the nonlinear optical properties of materials for novel infrared and optical microscopy. Two important methods have been devised. The first uses overtones (second harmonic) of illuminating light, as the overtones are

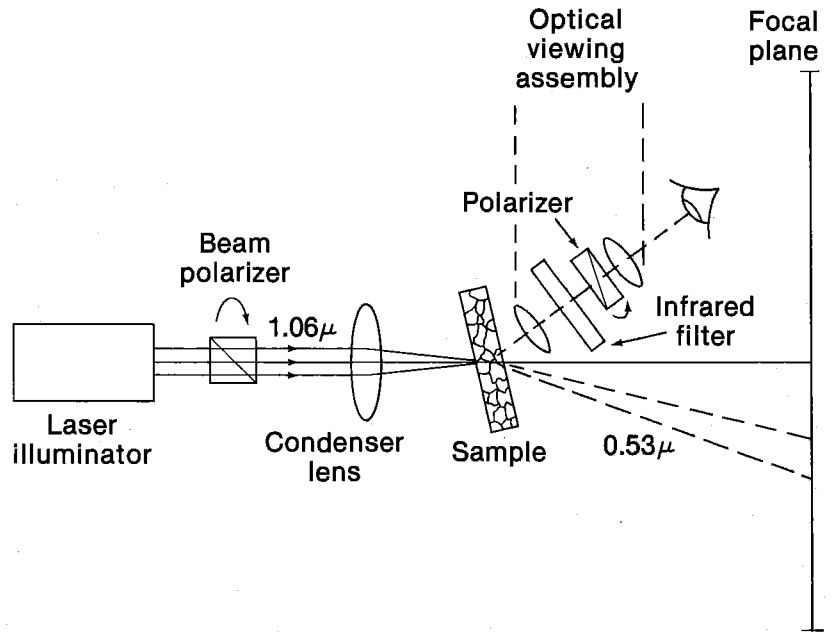


Cause of surface currents. A laboratory experiment in which a carefully instrumented slab of granite was stressed shows much higher surface currents at the mineral grain boundaries than within the grains. This result supports the theory that surface currents result from stress-induced migration of water and other mobile constituents of the rock and helps explain the chain of events that occurs before a rock fractures.

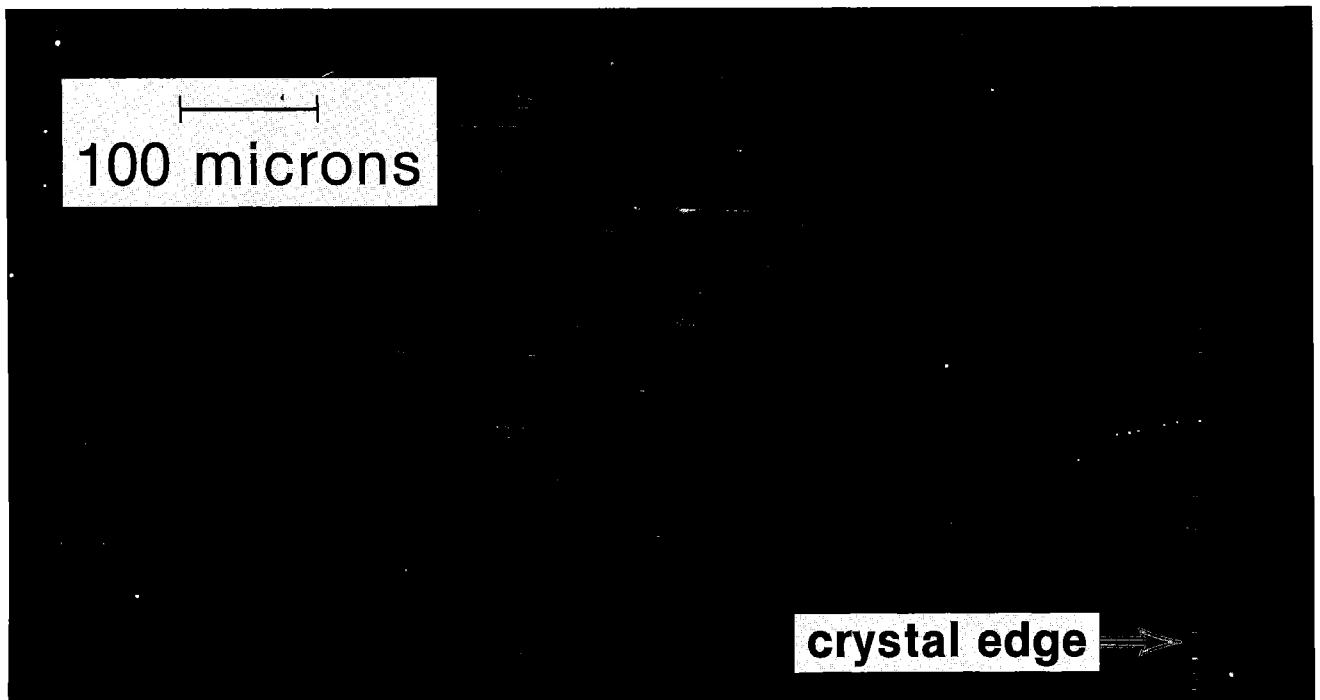
generated by certain materials, to observe the microstructure of transparent crystals. Such microstructure is invisible to conventional microscopy. In the second method, visible images of microstructure are formed by using the nonlinear refractive index present in all materials.

The basic principle of a nonlinear optical microscope may be understood by analogy to the familiar ordinary microscope. When a crystal is illuminated in an ordinary microscope, the illuminating beams are refracted or absorbed by the microstructure: inclusions, imperfections, inhomogeneities, and strains in the sample. Lenses capture and refocus the surviving light to form an image of the microstructure in the eye or on film. However, some microstructure neither refracts nor absorbs light under ordinary circumstances.

An example of such structure are the clusters (domains) of barium titanate molecules that are aligned antiparallel (180°) to the rest of the molecules in the crystal. These domains refract and absorb light identically as do the other



Seeing the invisible. (Above) A new kind of microscope uses an infrared laser for illumination and observes overtones, or harmonics, of the light generated within the sample. (Below) A thin crystal of "perfect" barium titanate, when seen with this microscope, reveals rod-shaped domains invisible to ordinary light. These domains respond to electric fields and have possible applications to computer memories. The nonlinear optical concepts involved in the new microscope are also important to image and signal processing.



molecules and do not alter the course of any light beams. However, these domains exhibit quite different nonlinear optical effects from the surrounding crystal. For example, the second harmonic (one-half the illuminating wavelength) generated in the 180° domain is 180° "out of step" with the light generated in the surrounding crystal; such light rays are easily refocused to create magnificent images of the domains.

When Hellwarth directed an infrared laser beam into a perfect crystal of barium titanate in its ferroelectric phase at room temperature, microscopic green stria (small rodlike domains) became visible due to the refraction of the second harmonic of the laser frequency. This crystal, when viewed through an ordinary microscope, had revealed no structure with conventional optical illumination. Now that the domains have been made visible without surface treatments, their behavior under applied fields, strains, and temperature gradients can be easily studied.

Unfortunately, only certain types of microstructure generate harmonic light readily. Hellwarth has proposed and verified another form of nonlinear effect (nonlinear refraction), which all types of matter possess, to generate images of otherwise invisible structure. This effect makes use of the fact that the light-bending power of a medium changes under high-power laser illumination. Images formed by nonlinear refraction can be restorations of images that have been badly altered while propagating through distorting media. This capability is completely outside the range of conventional microscopes.

Microfabrication

Researchers at the University of Pennsylvania have demonstrated a new microfabrication technique that may affect future methods for making electronic devices and other structures. The technique is part of the

lithographic process that is used in making integrated circuits and other applications when precise patterns must be replicated on a surface. In the case of the integrated circuits, the patterns correspond to the regions over which certain materials are to be diffused into the surface of a semiconductor to make transistors or the regions over which a metallic layer is to be plated to make transistor interconnections. A number of different patterns are needed to make a single integrated circuit. The patterns are formed in a special coating (called a "resist") by exposing the material to light. This is done through a mask that contains an original version of the pattern to be replicated. The altered resist material is then selectively removed from the exposed regions to facilitate such processes as diffusion and metal deposition.

What Mark Chang and his group at Pennsylvania have shown is that certain inorganic compounds can be used as resist materials. Working with amorphous compounds of arsenic and sulphur (As_2S_3), they have succeeded in demonstrating both the exposure and the selective etching steps in the lithographic process. Their most important contribution has been to show that the material could be etched with the aid of a plasma discharge in what is termed dry processing. This means that chemical etchants whose use increases fabrication process difficulties are not needed for the inorganic resists.

The significance of this research lies in the potential new options it provides for fabrication of future generations of electronic devices with identifiable features well below the 1-micron dimensional range. The As_2S_3 resist is deposited by evaporation rather than by spreading a liquid, as is done presently. This means that covering a step or other feature on the surface may be easier to accomplish. It should also be possible to use thinner resist films. The thinner the resist film, the easier it is to define patterns that have the very

small feature size needed for future microcircuits. In addition, by broadening the range of materials that can be used for resist, it should be possible to avoid certain chemical interactions that can have a deleterious effect on the electrical properties of devices being fabricated. The lithographic process being investigated by Chang does not involve any oxygen-containing compounds, for example, so that oxidation of metals can be avoided. This factor may prove to be of particular importance in the fabrication of superconductive devices that use niobium films that are very sensitive to oxidation.

In a series of experiments intended to quantify properties of the material, the University of Pennsylvania group has been replicating gratings in the inorganic resist. The sensitivity of the resist is examined by exposing it to different intensities of ultraviolet light and by illuminating the resist with a laser beam during plasma etching. As the grating is etched into the resist, the laser beam is diffracted. The diffraction efficiency of the grating provides quantitative data concerning etch rates and exposure sensitivity. So far, the inorganic resist parameters are not as good as those of the long established polymers used in wet processing techniques. However, in recent experiments, Chang's group has added a silver overlay to the inorganic resist and produced a greatly enhanced differential etching rate between optically exposed and unexposed regions. But this was done using a wet process, and new methods for improving the resist properties must be found.

Indirect Fractional Solidification: An Energy-Efficient Separation Process

Removing salt from seawater and catalyst poisons from chemical feedstock, distilling petroleum into its various fractions, purifying waste water

for reuse, and extracting minerals from ores and proteins from cheese whey are all examples of separation processes. All of these industrial chemical processes would be rendered useless if the reaction products could not be separated from the reacting mixture and from one another.

Conventional separation processes are highly energy-intensive because of the large amount of latent heats required to break molecules away from homogeneous mixtures; it has been estimated that separations operations account for 75 to 80 percent of the energy consumed in a typical process plant. In 1976 a conservative estimate put energy consumption by distillation operations alone at 10^{15} BTU—3 percent of the total national energy consumption. A 10-percent reduction of this energy requirement, either by an alternate procedure or by improving the efficiency of the distillation process, would mean a savings of some 100,000 barrels of oil a day, or \$500 million annually.

Fractional solidification is such an alternative. It separates a liquid mixture into relatively pure components by crystallizing selected components based on differences in freezing points.

Basically, the fractional solidification process consists of three functional steps: (1) a freezing step in which the feed solution is partially frozen by removing the heat of crystallization; (2) a washing step in which the solid formed in the freezing step is purified by washing it free of adhering solutions; and (3) a melting step in which the purified solid is converted to a liquid product by supplying the heat of fusion. However, the process also has some serious disadvantages which have prevented its widespread application. They are: (1) low actual separation efficiencies; (2) high equipment and operating costs; and (3) operational difficulties.

Chen-Yen Cheng and his chemical engineering research team at the University of New Mexico have made major advances toward overcoming

these problems. Their initial studies had shown that the low actual efficiency was caused by the solution entrapped in the interstitial voids in the crystalline solid formed on the vessel walls; the cost factors were associated with mechanical removal of the crystalline solids, low heat transfer rates, and inadequate heat reuse. To solve these problems Cheng designed a novel multiconduit freezer-melter with two sets of quarter-inch tubes that are alternately used as freezer and melter so that, while freezing operation is conducted in one set of tubes, melting is in progress in the other. A great energy saving is realized by effectively reusing the heat released in the freezing operation for supplying the heat needed for melting in the neighboring

tubes, and the temperature differential required in heat reuse is obtained by maintaining the two sets of tubes under two different pressures. The refrigeration energy input thus required is only 5 to 10 percent of that necessary without the heat reuse.

The fractional solidification concept is useful both in accomplishing a high degree of separation of concentrated solution (the dendritic deposit approach) as well as in superpurification of a dilute solution (the smooth deposit approach). The New Mexico group's current research is emphasizing the analysis of these two fractional crystallization processes in order to provide a guide for determining the range of operating conditions for any desired separation.

Materials Research

Materials research seeks to advance fundamental and conceptual knowledge and understanding of materials through the study of the properties that govern their physical, chemical, and mechanical behavior. In recent years considerable effort has been made to provide the materials community with new, sophisticated research equipment. In the past year, not only has equipment serving the needs of individuals or small groups been provided, but construction has begun on four major projects: the expansion of the synchrotron radiation facility at Stanford University to increase the U.S. capability in providing a tunable source of hard X-rays; the construction of the 1-GeV (billion electron volts) Aladdin storage ring at the University of Wisconsin, where soft X-rays and vacuum ultraviolet radiation will be available to users; the installation of a very high energy X-ray source at the Cornell High Energy Synchrotron Source; and the development of the National Research Facility

for Small-Angle Neutron Scattering at Oak Ridge National Laboratory. These facilities, which are all expected to be in operation by 1980, will serve a broad spectrum of investigators in science and engineering drawn from the disciplines of biology, chemistry, physics, electronics, and materials.

Although the materials research supported by NSF is devoted entirely to improving the understanding of fundamental principles, a number of investigations have provided information potentially important to technological progress. For example: Superconducting, A-15-structure compounds with high transition temperatures are very brittle; their brittleness has made difficult their development into technological materials—windings for superconducting magnets, for instance. Hence, there is interest in obtaining high critical- or transition-temperature superconducting materials that are ductile. G. W. Webb at the University of California, San Diego, has

found, from his basic phase diagram studies, that it is possible to quench gram quantities of the niobium-aluminum alloy, Nb_3Al , into a ductile body-centered cubic (bcc) structure. While in the bcc structure, it can be cold-worked and then converted by annealing to the brittle but superconducting A-15 structure. Other investigations had shown that Nb_3Al could be prepared in the body-centered cubic structure by splat quenching from the liquid state, but only as a very fine grained material. The important aspect of these early results is that this spin-off from basic studies of materials may open the path for large-scale technological application of these superconducting compounds.

Fluorescence is rapidly becoming a powerful tool in the study of polymers. Because the energy transfer processes in fluorescence require that light-absorbing groups of the molecules (chromophores) be in a specific spatial arrangement with respect to each other, the photochemical behavior of polymers can be an enormously useful method in the investigation of the behavior of polymer chains. Herbert Morawetz of the Polytechnic Institute of New York has recently used a variation of this method—*nonradiative energy transfer*—to study the complex problem of determining the extent to which polymer chains interpenetrate each other. It is known that the excitation energy of a chromophore can be transferred over distances up to 50 angstroms if the emission spectrum of a "donor" chromophore overlaps that of an "acceptor." Thus, light absorbed by the donor can be emitted by the acceptor, and the efficiency of this transfer is a measure of the distance between the two.

Morawetz used this technique to measure the ways in which chains of polymethyl methacrylate intertwine with a chemically close relative known as methacrylate-butyl acrylate copolymer. By introducing about 1 percent of anthryl chromophores in the former and the same concentration of naph-

thyl chromophores in the latter, Morawetz was able to demonstrate not only that there was interpenetration, but also the extent to which it took place. These findings have some favorable implications for the development of polymer mixtures, a subject of considerable interest in connection with the recycling of plastics.

Glass is closer in composition to the Earth's crust than is any other synthetic material, and hence comes from a virtually unlimited source. Further, the energy required per unit volume to melt glass is only a ninth as great as that required to produce aluminum. Since the work in 1920 of A. A. Griffith, who recognized that the mechanical weakness of glass was not an intrinsic property, but rather due to the existence of superficial stress-concentrating flaws, considerable progress has been made in realizing some of the potential strength of glass as a structural material.

The most promising approach for bulk glass seems to be the development of residual compressive stresses on the surface that will diminish the possibility of a net tensile stress operating to extend flaws. Many methods exist for achieving this residual stress, but ion-exchange strengthening yields the highest stresses and, hence, is the most interesting if one wishes to optimize the mechanical properties of glass.

The disadvantage of usual ion-exchange strengthening is that it is a slow process. However, A. R. Cooper at Case Western Reserve University has found that, utilizing a moderate electric field to drive the exchanging ions into the glass, he can greatly reduce the treatment time and energy cost while producing a layer of nearly uniform compressive stress. Furthermore, even after mild abrasion, which usually degrades the strength of a brittle material, such treated glass maintains a fracture strength three or four times as great as the yield strength of low-carbon steel. Discovery of the new treatment thus paves the way for preparing stronger,

abrasion-resistant structural glasses.

One of the most important and yet most difficult problems in surface science is the determination of the bond-length of an atom adsorbed on a solid surface. The question has important implications for catalysis and corrosion studies involving oxygen and other light elements. Metallic corrosion results in an estimated annual loss to the U.S. economy of \$70 billion. Joachim Stöhr at the Stanford Synchrotron Radiation Laboratory (SSRL) has observed Extended X-ray Absorption Fine Structure (EXAFS) from surface atoms, a process that provides a direct measure of the atom-to-surface bond length. (EXAFS is a powerful technique by which the interatomic distances between an atom and its near neighbors can be measured with high accuracy. By detecting the rate at which electrons are given off from the sample when monoenergetic X-rays are swept through the characteristic X-ray absorption edge of the surface atom, EXAFS can be observed.) Stöhr, of the SSRL staff, measured the rate at which photoelectrons are given off by oxygen adsorbed on an aluminum surface as the incident X-ray energy is swept through the characteristic absorption edge of oxygen. He observed the EXAFS oscillations and was able to determine the oxygen-aluminum distance. The EXAFS in the study was clearly related to the surface atoms; electrons from atoms in the bulk undergo many interactions on the way to the surface and cannot escape the crystal.

It has long been known that lithium additions to aluminum and its alloys result in much increased strength but simultaneously reduce the toughness and seriously decrease fatigue life. This is due to the segregation of lithium-rich intermetallic compounds during conventional ingot solidification. Such segregation was known to be minimized—and in some cases suppressed—by increasing the solidification rates by, for instance, splat quenching from the melt. N. J. Grant

and coworkers at MIT have roller-quenched such lithium-containing alloys directly from the melt to thin foils with quenching rates up to 100,000 degrees Centigrade/second, some seven orders of magnitude higher than those common in conventional practice. These foils were then extruded to fully dense rods, the extrusion process providing complete densification. Microstructural characterization of the product confirmed the major improvement in the quantity of the intermetallic compounds precipitated, especially in the size and distribution of the precipitate, at 1 percent and 3 percent lithium concentration. In one of the alloys (2024, 4.5-percent copper, 1.6-percent magnesium) the resulting properties were found: (1) yield (at 1-percent strain) and ultimate (maximum) strength levels were both increased by some 50 percent; (2) elastic and shear moduli were increased by some 20 percent and the density decreased slightly, significantly improving the strength and elastic parameters per unit weight—an important structural characteristic; (3) the fatigue stress for a life of 10 million cycles increased by 65 percent; and (4) ductility remained at acceptable levels, although some decrease was observed corresponding to the increased strength.

Diffusion of Gases on Single Crystal Planes

Considerable progress has been made during the past decade in characterizing the structure and properties of chemisorbed layers on single crystal surfaces. One important aspect of chemisorption on metals—diffusive transport in such layers—has not been addressed successfully in the past because of significant experimental difficulties. Surface diffusion is, however, of considerable fundamental and applied importance: Diffusion can provide insights into the properties of the gas-metal bond. Information about the

transport of gases over metals is important for a better understanding of such surface reactions as heterogeneous catalysis and corrosion.

Gert Ehrlich and students at the University of Illinois at Urbana have perfected a technique that makes such measurements possible. In their method, the single crystal plane to be studied is cooled to cryogenic temperatures and exposed to a molecular gas which adsorbs, without dissociation, over the entire surface. To form a localized deposit of atoms for diffusion studies, a selected portion of the surface is heavily irradiated with a low energy beam of electrons. The electron beam dissociates adsorbed molecules, forming a deposit of atoms in the desired shape. The molecular gas which has not been irradiated can be removed by gentle warming, leaving behind a well defined, localized deposit of chemisorbed gas. The electron beam, at reduced current levels, is then used to monitor diffusion from this initial deposit. As the electron beam scans across the surface, the Auger spectrum of the surface layer is recorded to yield the concentration profile of the diffusing gas. Such measurements, taken at different times and temperatures, serve to define the entire diffusion process.

The first direct measurements were of nitrogen on the surface of a tungsten crystal. The spreading of such a deposit has been measured at a series of temperatures. These experiments revealed that a barrier of 21 kilocalories per mole opposes the hopping of nitrogen atoms over the surface plane. The desorption energy of nitrogen from the same tungsten plane was determined to be 79 kilocalories per mole, indicating that motion of atoms parallel to the surface is easily compared to excursions away from the surface.

These measurements have established the power of this electron beam technique. They suggest that motion over low index planes occurs more rapidly than over atomically rough

surfaces. It now remains to explore surface diffusion systematically in order to establish the material parameters affecting transport in chemisorbed layers and to examine systems of more direct interest for catalysis and corrosion.

Electron Spin-Polarization on a Nickel Surface

For many years, since the first measurements of spin-polarization at the surface of a magnetic metal, there has been a serious discrepancy between theory and experiment and a consequent barrier to research programs important to catalysis and chemisorption studies. The field emission results found a polarization qualitatively different from that predicted by electronic energy band theory. In fact, the experiments showed that the emitted electrons had a total spin-polarization *opposite* to that theoretically predicted. This discrepancy was confirmed by further experiments using techniques of photoemission (done at the Technische Hochschule in Zurich, Switzerland) and tunneling (done at the National Magnet Laboratory under the direction of R. H. Meservey and coworkers).

Recently, Leonard Kleinman and coworkers at the University of Texas have shown by means of parameterized thin-film calculations involving up to 47 layers of atoms that extra electronic states are predicted to occur at the surface of a nickel crystal, which can explain the anomalous spin reversal in the photoemission results. When the actual electron spin-polarization is calculated as a function of incident photon energy, the results are in quantitative agreement with experiments on a face (called 100) of a nickel crystal. Kleinman's initial calculations, however, showed a discrepancy for a different face (called 111) of the nickel crystal.

A possible source of this discrepancy was indicated in the results of a related

experiment by D. E. Eastman of IBM and coworkers, using the facilities of the Wisconsin Synchrotron Radiation Center. Their observation of the angle-resolved photoemission spectrum of a nickel surface gives the first direct measurement of the momentum dependence of the energy band structure of a crystal. One of the results to come out of this investigation was an estimate of the difference of energies between electrons of opposite spin (exchange splitting). The estimate was significantly smaller than the theoretical prediction.

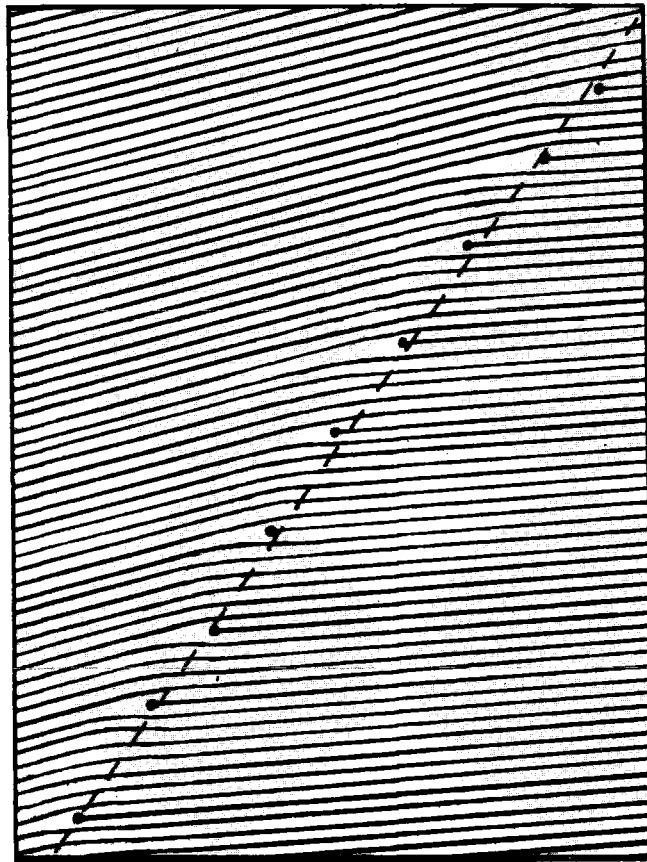
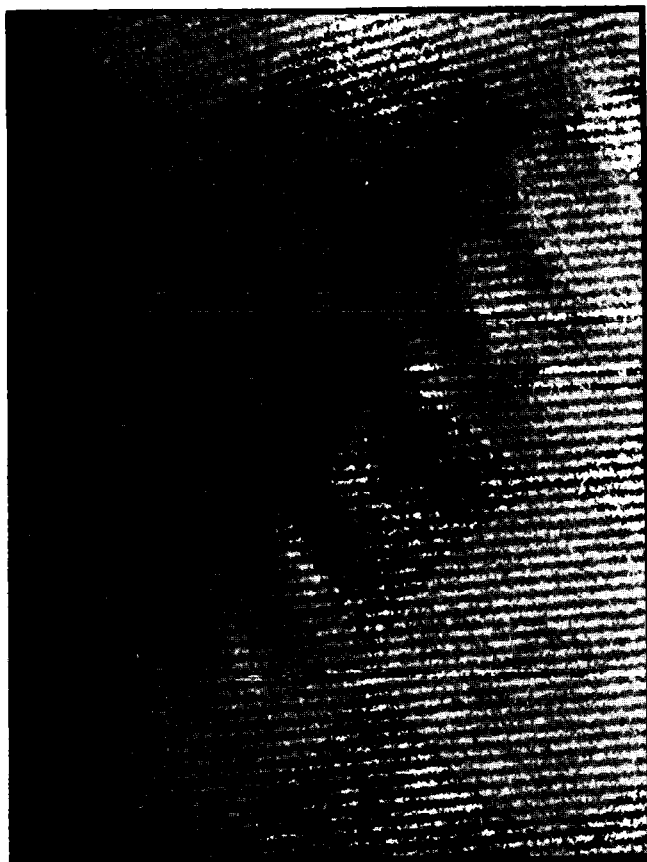
When Kleinman used Eastman's measured exchange rather than the theoretical value as a parameter in his

calculation, the discrepancy on the (111) face was resolved. The IBM/Wisconsin experiments also gave the first measurement of the temperature dependence of the exchange splitting in a ferromagnetic metal. This showed a variation intermediate between that predicted by the localized and itinerant (i.e., energy band) models.

All of these results are significantly changing the way in which the surface electronic structure is pictured. Since the magnetic transition elements like nickel are often used as catalysts, these new developments will have a strong impact on future theoretical and experimental work on chemisorption and catalysis.

Characterization of Lattice Defects by High Resolution Electron Microscopy

All structural metals, alloys, and ceramics are polycrystalline aggregates—i.e., they contain grain boundaries. The important engineering properties—such as strength, fatigue life, and corrosion—are strongly dependent on the properties of grain boundaries. Work by scientists at Carnegie-Mellon and Cornell Universities promises answers to many unresolved questions concerning atomic structure and concomitant properties of grain boundaries in metals.



Lattice defects. A 10-degree misorientation in alignment of lattice planes across a grain boundary in gold is magnified 8 million times (left) as a result of a new observational technique. A drawing (right) identifies the grain boundary (broken line) and the terminations of nine individual lattice planes (dots). These terminations accommodate misorientation between grains and are important to materials' properties such as strength and vulnerability to fatigue.

Through collaboration of C. L. Bauer at Carnegie-Mellon and S. L. Sass at Cornell, terminations of individual lattice planes within especially prepared thin films of gold have been observed by an electron interference technique termed lattice imaging. Termination of lattice planes occur frequently in crystalline solids in order to accommodate misorientation between grains. They also define the precise position of a grain boundary. Grain boundaries of specific orientation were obtained (at Carnegie-Mellon) by vapor deposition of gold onto sodium chloride bicrystals having preselected grain boundary orientations. The gold microlayer copied the grain boundary angle of the substrate; when the substrate was dissolved in water, the cop-

ied boundary layer angle on the thin gold film remained. It was examined (at Cornell) by high resolution electron microscopy. The Cornell electron microscope, at the Materials Research Laboratory central facility there, provided the necessary high level of resolution.

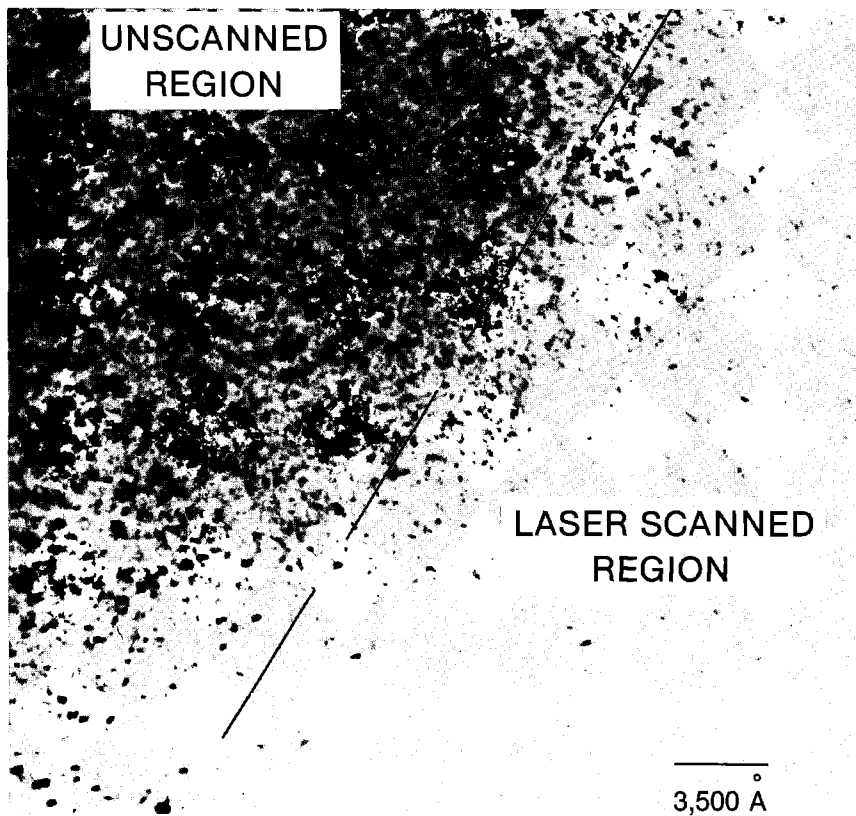
Among the results: A 10-degree misorientation of lattice planes across a grain boundary (oriented diagonally) in a thin film of gold was revealed at a magnification of 8,000,000, and termination of lattice planes and position of the grain boundary were readily discernible. Such terminations represent lattice defects, called dislocations. Through careful quantitative analysis, these defects may be characterized precisely and subsequently related to

light and dark contrast patterns superposed on the grain boundary. Advantages of the technique are that many types of grain boundaries may be preselected for study and subsequently produced in an edge-on configuration in bicrystalline films of thicknesses that satisfy necessary diffraction and contrast conditions.

Laser Annealing of Ion-Implanted Semiconductors

Ion implantation is a powerful technique for producing the necessary p-n junctions in semiconductors. The implantation in silicon of impurities such as boron or arsenic is done by injecting high energy ions of these elements into surface layers of the semiconductor. However, this implantation causes damage to the semiconductor's crystal lattice, leaving dislocation, stacking faults, and point defect clusters which act as undesirable traps for holes and electrons. A high temperature thermal annealing step is conventionally used to remove this damage, but some defects remain and, often, the electrical properties are degraded by the thermal anneal.

J. F. Gibbons and his colleagues at Stanford University, together with scientists in other laboratories, have devised laser annealing techniques whereby the damage of the implanted layer is removed without changing the impurity profile. The Stanford group, beginning in January 1976, pioneered annealing with scanned continuous wave (CW) lasers. This removes damage but does not melt the surface as happens when a pulsed laser is used. Scanning CW systems also have several other advantages over pulsed systems: (1) the CW laser beam is free of hot spots and other technical defects that can cause variability in results, and (2) a scanning system readily permits annealing of selected areas on a large wafer, an advantage that can be of great interest to integrated circuit



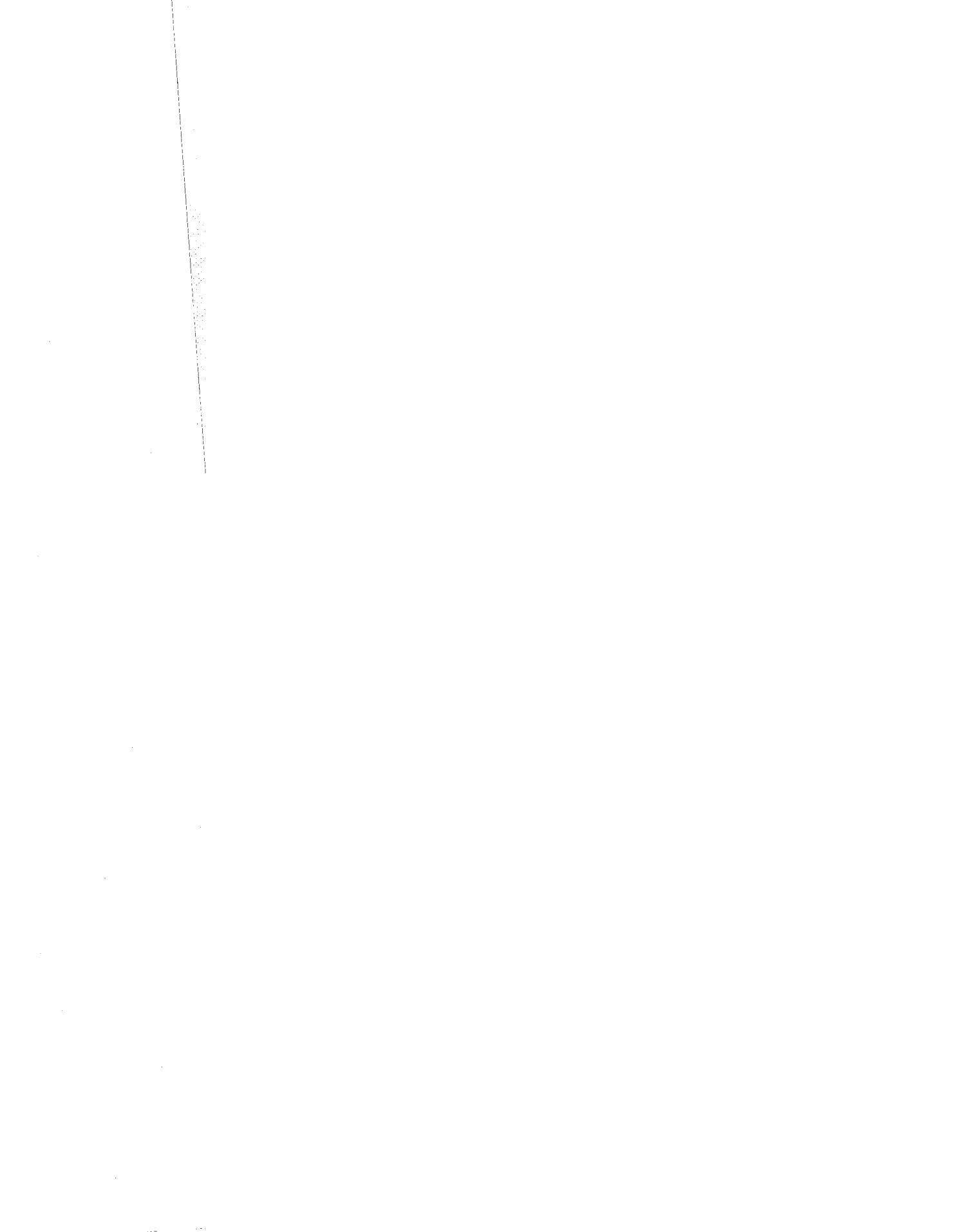
Advanced semiconductors. A newly developed laser annealing technique for removing crystal defects in semiconductor materials promises great advantages over conventional annealing by heat. This transmission electron micrograph shows how the laser removes damage (which shows up as dark spots) in boron-implanted silicon.

manufacturers. Gibbons found, for both boron-implanted silicon and arsenic-implanted silicon, that scanning CW laser annealing not only removed damage but also preserved 100

percent of the electrical activity and a carrier mobility equal to the theoretical value.

The lack of diffusive redistribution of the implanted ions during CW laser

annealing is expected to lead to significant future improvements in the design and fabrication of high-performance transistors, integrated circuits, and solar cells.





Astronomical, Atmospheric, Earth, and Ocean Sciences



NSF's programs in the Astronomical, Atmospheric, Earth, and Ocean Sciences provide support in selected disciplines to increase our knowledge of the physical environment, both on Earth and in space. The overall objectives of the various programs are to obtain new knowledge encompassing the broadest possible scope of natural phenomena in the astronomical and atmospheric sciences; to provide greater understanding of the physical, chemical, and biological composition of the Earth; to develop further insight into the nature of the ocean and the interaction taking place between the human and marine environments as human activities become increasingly involved with and dependent on the oceans; and to advance our knowledge of the environment and resources of the Earth's polar regions.

NSF is responsible for the U.S. Antarctic Program, through which the United States supports the goals of the Antarctic Treaty and maintains a U.S. presence in Antarctica as an accompaniment to its international cooperation in scientific programs. In this context NSF has the overall management responsibility for planning, funding, and implementing the program.

The Foundation is the predominant source of support for ground-based astronomy in the United States. This support is provided through research grants to academic institutions and contracts with consortia and single universities for the operation of five

Table 2
Astronomical, Atmospheric, Earth, and Ocean Sciences*
Fiscal Years 1976, Transition Quarter
(July 1-Sept. 30, 1976), 1977, and 1978

(Dollars in Millions)

	Fiscal Year 1976		Transition Quarter		Fiscal Year 1977		Fiscal Year 1978	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Astronomy	201	\$ 11.13	70	\$ 4.67	222	\$ 13.48	227	\$ 15.65
Solar Eclipse Support.....	1	0.06	0-	0-	0-	0-	0-	0-
Atmospheric Sciences	237	14.91	49	2.82	276	17.66	295	20.15
Global Atmospheric Research Program.....	68	3.81	10	1.00	67	4.46	69	5.28
Climate Dynamics	31	1.98	16	1.00	59	3.97	70	4.31
Earth Sciences	296	15.29	117	4.23	325	16.26	442	20.67
Ocean Sediment Caring Program	5	11.83	1	3.50	4	12.80	5	13.40
Oceanography	320	15.65	89	4.54	322	17.70	351	19.00
International Decade of Ocean Exploration.....	179	15.42	26	3.38	190	17.16	234	18.37
Oceanographic Facilities and Support.....	70	16.01	14	1.00	69	18.39	70	20.81
U.S. Antarctic Program	106**	49.58***	89**	13.43	115**	45.29	132**	48.45
Arctic Research Program	46	3.62	7	1.30	58	4.62	78	5.34
Total	1,560	\$158.29	488	\$40.87	1,707	\$171.79	1,968	\$191.43

*Excludes National Research Centers
 **Science Awards. Excludes operations support awards.
 ***Includes \$18.0 million for procurement of two ski-equipped aircraft.

SOURCE: Fiscal Years 1978, 1979, and 1980 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

national astronomy observatories. Many of the world's largest and most advanced telescopes are located at these observatories. Scientists compete for free observing time at the national observatories, enabling astronomers at universities without research telescopes to undertake major research programs.

Among the significant events in as-

tronomy during the past year were the discoveries at Kitt Peak National Observatory of a star soon (2,000 years) after its birth and the 300,000-year-old gaseous remains of a supernova in our galaxy; new instrumentation developments to increase the capabilities of existing telescopes; and the operation of half of the 27 antennas of the Very Large Array, already the world's

Table 3
Astronomical, Atmospheric, Earth, and Ocean Sciences
National Research Centers
Fiscal Years 1976, Transition Quarter
(July 1–Sept. 30, 1976), 1977, and 1978

(Dollars in Millions)

	Fiscal Year 1976	Transition Quarter	Fiscal Year 1977	Fiscal Year 1978
National Astronomy and Ionosphere Center	\$ 4.05	\$ 1.10	\$ 3.90	\$ 5.48
Kitt Peak National Observatory	8.40	2.15	8.70	9.13
Cerro Tololo Inter-American Observatory	3.45	0.90	3.50	3.88
National Radio Astronomy Observatory	21.55	3.50	21.80	22.14
National Center for Atmospheric Research	23.83	4.84	23.04	24.90
National Scientific Balloon Facility	*	*	*	1.77
Sacramento Peak Observatory	**	**	0.80	1.30
Total	\$61.28	\$12.49	\$61.74	\$68.60

*Included under the National Center for Atmospheric Research in previous years.

**NSF assumed funding responsibility for Sacramento Peak Observatory in fiscal year 1977.

SOURCE: Fiscal Years 1978, 1979, and 1980 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

most powerful and precise radio interferometer (and, in its present stage of completion, having a resolving power equivalent to that of the largest optical telescopes). Advances in instrumentation and improved facilities achieved during 1978 will undoubtedly have a profound effect in the coming years on the productivity of both optical and radio astronomy.

The Foundation supports research in the atmospheric sciences through grants to U.S. academic institutions and contracts for the operation of the National Center for Atmospheric Research in Boulder, Colo., a national research center dedicated to large-scale atmospheric research projects. International cooperation in atmospheric research by the U.S. scientific community is fostered through Foundation support of the Global Atmospheric Research Program and the International Magnetospheric Study (IMS). Important research results during 1978 include discoveries in solar terrestrial studies that will enable forecasting both the occurrence and

the intensity of major auroral activities about 2 hours before they begin; significant progress in the detection of downbursts in and around major airports and cities, which can result in improved safety in aircraft takeoffs and landings; and a new capability for investigating upper atmosphere dynamics with the most powerful radar yet constructed for studying the properties of the upper atmosphere and ionosphere at high latitudes. The radar was assembled as a key component in the IMS to study that part of our nearby space environment controlled by the Earth's extended magnetic field.

The earth sciences are now at the point where a great deal of knowledge exists about certain features of the Earth and where new instruments capable of unprecedented precision permit reaching to the limits of the environment. Though the theory of plate tectonics presently dominates the science, NSF support of geology ranges widely, from the measurement of rates of erosion to the history of organic evolution, and from the causes of gla-

cial epochs to the origin of diamonds. Real-time measurement of continental drift may soon be possible through a promising new technique originally developed for astronomy. Very Long Baseline Interferometry, initiated by MIT astronomers in 1967, can now be used to precisely measure wide distances between points on the Earth. The Deep Sea Drilling Project continued in 1978, and as a result of drilling across the Mariana Trough, the active Mariana Arc, and progressively deeper into the Mariana Trench to the east, we now have evidence that something similar to seafloor spreading has occurred behind the active island arcs.

The broad and complex nature of the oceans dictates that research in the marine sciences consist of multidisciplinary approaches that will examine closely interrelated processes and phenomena from the perspective of a total oceanic system. NSF's research programs in oceanography are playing a major role in providing the basic understanding of oceanic processes that will enable us to predict, and perhaps to control in some measure, the oceans' influence on humankind. Investigations in marine chemistry have pointed to a much stronger link between marine sediments and the ocean's nitrogen cycle than was previously supposed. In the living resources program of the International Decade of Ocean Exploration, analysis has revealed important information on plant and animal distributions in a coastal upwelling ecosystem. The oceanographic facilities and support program conducted in 1978 an in-depth study of the present status and future requirements of oceanographic instrumentation for the Nation's academic institutions having marine science programs. Also, concurrent with that study, a comprehensive inventory of oceanographic instrumentation and shipboard equipment was carried out to assess the maintenance and utilization policies and procedures for these costly facilities purchased with public funds.

About half of the U.S. support for arctic research is provided through various disciplinary programs of NSF and half through the Arctic research which is concerned primarily with environmental and resource-related investigations. The Foundation's year-round program of research in Antarctica, which is related to global scientific problems, is the principal expression of U.S. national policy in the antarctic region. This year an analysis of meteorites in Antarc-

tica revealed one type, which fell to Earth in great numbers during prehistoric time, with characteristics consistent with the possibility that it could have provided material making possible the emergence of life. Cruise number 17 of the research ship *Mas Orcadas*, operated jointly by the U.S. and Argentine Governments, was under way through September in the Scotia Sea for biological research directed primarily toward ecosystems analysis.

present incomplete form, the VLA has demonstrated the power of radio interferometry to produce radio wave "pictures" of galaxies and gaseous nebulae.

The number of visiting scientists using the National Astronomy and Ionosphere Center (NAIC) 1,000-foot-diameter (305-meter) radio/radar antenna in Puerto Rico has tripled in the last 3 years. The recently upgraded surface of the antenna makes it possible to perform high resolution radar mapping of nearby planets at a frequency of 2,380 MHz (megahertz). A third of the research at NAIC is devoted to radar backscatter study of the upper atmosphere.

During fiscal year 1978 NSF and the Association of Universities for Research in Astronomy (AURA), Inc., signed a 5-year contract for the operation of Sacramento Peak Observatory (SPO) in New Mexico as a national facility available to visiting scientists. The SPO tower telescope is well known for its ability to produce high spectral and spatial resolution observations of the Sun. These observations have been essential in the effort to understand the causes of solar storms, sunspots, and the of solar radiation that affects our climate on Earth.

NSF also supports research at several excellent university and private observatories. In April 1978 astronomers from the California Institute of Technology and Hale Observatories discovered three more rings around the planet Uranus, bringing the total number to eight. Uranus' rings are not directly observable; it was necessary to use infrared techniques at an excellent observing site to detect the telltale change in intensity of a faint star that passed behind the rings. The observations were made with the 2.5-meter-diameter du Pont telescope located at the Las Campanas Observatory in Chile.

At the Owens Valley Radio Observatory in California, a set of three small, identical millimeter wave telescopes are under construction. When

Astronomy

The Foundation is the lead Federal agency for ground-based astronomy in the United States; its activities are managed through grants for research by individual scientists and through the operation of five National Astronomy Centers. In the past year under the grants program, 227 principal investigators representing 65 universities and other institutions received awards for research in the areas of solar system astronomy, stellar systems and motions, stars and stellar evolution, galactic and extragalactic astronomy, and astronomical instrumentation development.

The majority of U.S. astronomers hold positions at universities that do not have research quality telescopes. Many of these scientists are nevertheless able to regularly conduct excellent research by traveling to the National Astronomy Centers. There, periods of observing time are available, without charge, on a competitive basis to field scientists. Many of the world's largest and most advanced telescopes are located at these observatories.

The 4-meter optical telescopes at Kitt Peak National Observatory (KPNO) in Arizona and Cerro Tololo Inter-American Observatory (CTIO) in Chile are among the world's most powerful visible light instruments.

These two telescopes were used extensively by visiting scientists in fiscal year 1978 for studies of very faint stars, nebulae, and galaxies. Discoveries at KPNO included a star soon after its birth (at 2,000 years, the youngest star known) and the discovery of the 300,000-year-old gaseous remains of a supernova in our galaxy.

The National Radio Astronomy Observatory (NRAO) 36-foot-diameter (11-meter) telescope in Arizona is the world's most sensitive millimeter wave instrument. It is at these millimeter wavelengths that many interstellar molecules of astrophysical interest emit their spectral signatures. Most of the 45 molecules known to date to exist beyond our solar system were discovered since 1967 with this heavily used telescope. Many are organic varieties, such as ammonia and ethyl alcohol; the two most recent detections by NRAO are NO and the radical

The newest major astronomical instrument in the United States is the Very Large (VLA), now under construction by NRAO in New Mexico. With half of its 27 antennas operating, it is already the world's most powerful and precise radio interferometer. It can now achieve a resolving power of 1 arc-second, equivalent to that of the largest optical telescopes. Even in its

completed, the three antennas will permit high resolution observations of interstellar molecular clouds, molecules in galaxies, and the births of stars.

Radio Spectrum Management

The Foundation assigns radio frequencies for the support of operations at the various National Astronomy Centers and also provides for use of the spectrum by grantees engaged in research activities such as radio and radar astronomy and meteorological remote sensing. In addition, NSF is working with other U.S. Government agencies in preparation for the forthcoming World Administrative Radio Conference, which will consider the projected requirements for spectrum allocations for radio astronomy and other services to the year 2000 and beyond. This conference, to be convened in late 1979 by the International Telecommunications Union, will be

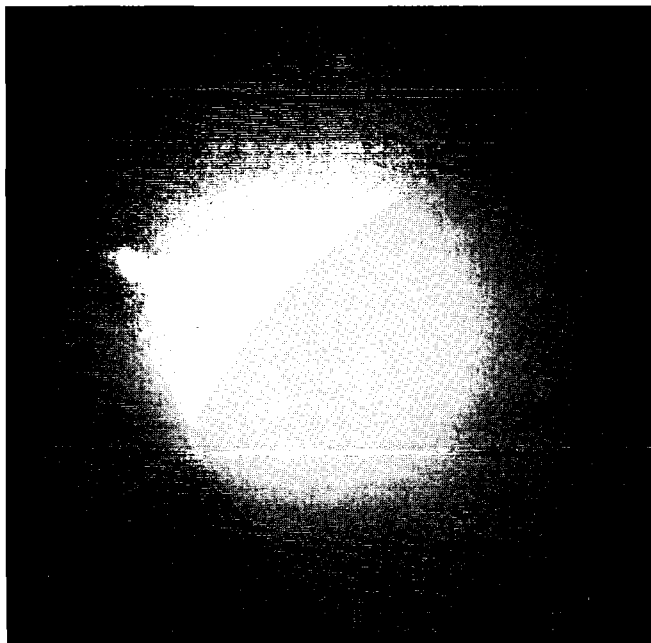
empowered to modify current Radio Regulations and the Table of Frequency Allocations. As the first truly comprehensive conference to do so in 20 years, it has the potential for making significant changes in the allocations. The outcome of the conference is expected to have a large impact on telecommunications and radio science throughout the world.

The development of position papers for the U.S. delegation to the conference is being undertaken by the Federal Communications Commission, the Interdepartmental Radio Advisory Committee (IRAC), and the National Telecommunications and Information Administration of the U.S. Department of Commerce. The NSF contribution is made primarily through the IRAC.

NSF also participates in an international technical advisory capacity through the Consultative Committee on International Radio and in deliberations of the Union of International Radio Science.

Evidence for a Supermassive Black Hole

Two groups of astronomers, using recently developed instruments at the Hale Observatories and at Kitt Peak National Observatory, have reported evidence for a dark compact mass in the center of the giant elliptical galaxy M87. The mass has all the characteristics of a black hole containing about five billion times the mass of the Sun. Since the 1960's, scientists have speculated that such supermassive black holes may be energy sources for the extremely powerful processes that occur in quasars, radio galaxies, Seyfert galaxies, BL Lac objects, and similar but weaker events in more normal galaxies. Large amounts of energy are known to be produced in very small volumes in these objects, a phenomenon hard to explain with normal astrophysical energy sources. Since black holes are compact and quite efficient in converting mass to energy,



Unseen component. Left—Galaxy M87, as photographed by Jerome Kristian and James Westfall using the Hale Observatories' 200-inch telescope, shows a jet extending away from the galaxy's center. Right—With the aid of a computer, P. J. Young "subtracted" the light representing the main body of the galaxy. What remained was the jet and an unexpected bright spot at the galaxy's center, which indicates additional, unseen mass there. Astronomers believe this may be a supermassive black hole.

they are very attractive from a theoretical point of view.

The direct detection of a black hole is difficult since it emits no light and is very small. Detection depends upon observations of indirect effects, such as the effect of its gravitational field on nearby visible masses. For example, much smaller black holes (several solar masses) have been postulated as the origin of X-rays from such sources as Cyg X-1; the evidence consists largely in the effect of the unseen mass upon a visible binary companion.

The Galaxy M87 is a prime candidate for a massive black hole search for a number of reasons. It is one of the brightest members of the Virgo cluster, the nearest of the great galaxy clusters, and, at a distance of about 60 million light-years, it is one of the nearest of the giant elliptical galaxies. Moreover, it is a radio source with very small components, an X-ray source, and contains a well-known jet emanating from the nucleus, suggesting the expulsion of matter or energy.

The first of the new observations was made by observers from the Hale Observatories and the Jet Propulsion Laboratory, using the 1.5-meter (60-inch) and the 5-meter (200-inch) telescopes at Palomar Mountain. They examined the distribution of light from the stars in the galaxy, using silicon-intensified television detectors that have been adapted to astronomical use. The investigation found a bright, sharp "spike" of light at the center of the galaxy, and a less obvious but very important excess of light within the central 10 arc-seconds of the nucleus. This excess light in the central region cannot be explained by otherwise successful theories of elliptical galaxies, which assume that the galaxies are made up entirely of stars moving under their mutual gravitational attractions. The new observations indicate that there must be an additional unseen component of M87 located at its center.

Other observations were made with the 4-meter KPNO telescope by ob-

servers from the Hale Observatories, University College, London, KPNO, and the University of Victoria, British Columbia, Canada. They obtained high resolution spectrograms at a number of places in the galaxy, using a device known as the image photon counting system. The spectrograms were used to determine the velocity dispersion, which arises from the motions of stars within the galaxy and is a measure of the mass distribution. The data show a sharp increase in velocity dispersion toward the center of M87, not seen in other galaxies, which points to the existence of an excess mass at the galaxy's center.

By combining the Palomar and KPNO data, astronomers can describe the mass distribution of M87 in a way that is independent of galaxy models; they assume only that the visible stars obey the basic laws of dynamics under the gravitational influence of whatever masses may be present.

The result leads to the conclusion that the nucleus of M87 contains a dark, compact mass. The total mass within the central 1 arc-second (300 light-years) of the galaxy is 5 billion times the mass of the Sun. This mass is no more than one-tenth as bright as the stars that make up the rest of the galaxy; it has a mass-to-light ratio of at least 60 to 1, in solar units, while the rest of the galaxy has a ratio of 6 to 1. All of the existing data are consistent with the presence of a central black hole of several billion solar masses. Furthermore, if such a black hole is present, it could produce enough energy by consuming stars and stellar debris to fuel the radiation in the jet and in radio and X-rays.

While the observations do not conclusively confirm the existence of a supermassive black hole at the center of M87, they are the best evidence for such an object so far. Whatever the nature of the compact dark mass, it is very peculiar compared with normal galaxies. In many ways a black hole is the most plausible explanation of the observations.

Optical Bursts From an X-Ray Burst Source

The original discovery of X-ray sources in space that exhibit the phenomenon known as X-ray bursts took place in December 1975. Since that time more than 30 such sources (known as "bursters") have been identified. All are located in the plane of our Milky Way galaxy, the majority of them within 35 degrees of the galactic center. At least two of the sources are located in globular clusters (a spherical clustering of about 100,000 stars), and three of the sources have been identified with faint blue stars.

The mechanism that produces the X-ray flux is not known. The X-ray burst rises to peak intensity within a few seconds and lasts several seconds to minutes. The bursts are emitted at almost regular intervals, ranging from hours to days. At least eight sources emit a persistent but variable X-ray flux. It has been suggested that the burst sources are either neutron stars or black holes of stellar mass.

One faint blue star identified as an optical counterpart of an X-ray source is known as MX3 1735-44. Because the detection of bursts in other parts of the spectrum (radio, infrared, or optical) could place significant limits on the physical conditions at the source and provide tests of various models, astronomers at Cerro Tololo Inter-American Observatory monitored this stellarlike object optically with the 1.5-meter telescope for 3 days during June 1978. Simultaneous X-ray observations were made with the orbiting X-ray observatory SAS-3, which maintained continuous pointing to keep the object centered in the field of view of its X-ray detectors.

The result was a confirmed correlation between an optical and X-ray burst. Analysis of observing data shows that the optically detected burst must come from an emitting region located within 1 to 2 light-seconds of the X-ray source. The region itself must be less than 1 to 2 light-seconds

(about 300- to 600,000 kilometers) in extent.

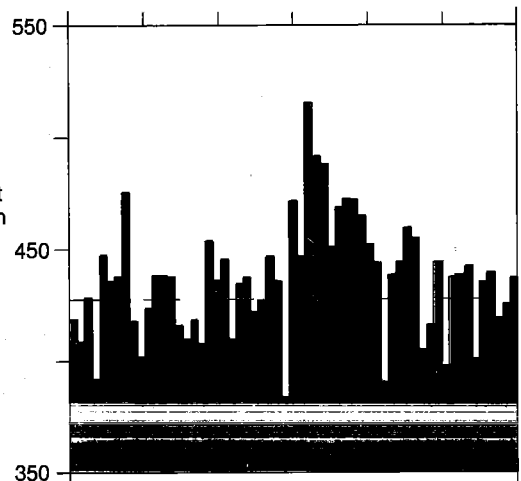
These results do not, by themselves, eliminate any proposed models. The results do show, however, that if the X-ray burst source is in a binary (two-star) system, the companion of this strange source is either shielded from its X-ray emission or, if unshielded, sufficiently separated from it so that its optical emission is small. This discovery of simultaneous optical and X-ray bursts from these very strange objects paves the way for further simultaneous observations as astronomers seek a physical explanation of these objects.

New Constraints on Physical Laws and Matter in the Early Universe

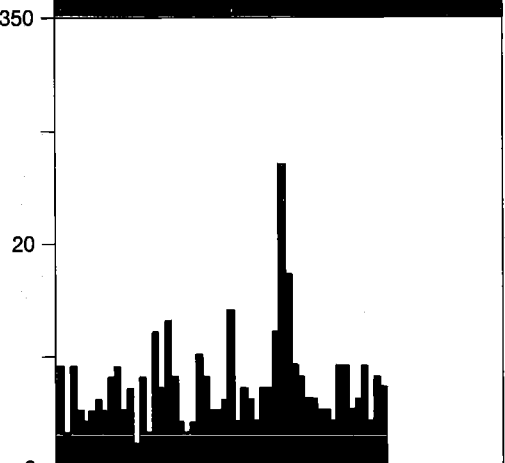
The detection by two astronomers from the University of Pittsburgh and the National Astronomy and Ionosphere Center in Arecibo, Puerto Rico, of an extremely faint dip in the continuous emission spectrum of the quasar 1331+17 confirms that our physical "constants" have indeed remained unchanged over at least two-thirds of the age of the universe. In addition, the observation, made at Arecibo in March 1978, is unique in providing a direct measurement of an unexpectedly high temperature in the hydrogen gas responsible for the observed adsorption. These observations indicate the high probability that an intrinsic rather than chance relationship exists between the emitting and absorbing material, in spite of the redshift difference between them. Both results have far-reaching consequences for our understanding of the early universe.

Quasars are the most distant known objects in the universe. These highly luminous, extremely compact systems produce copious quantities of both optical and radio radiation. Shortly after the discovery of quasars, it was noted that many quasar spectra, when observed with high dispersion optical

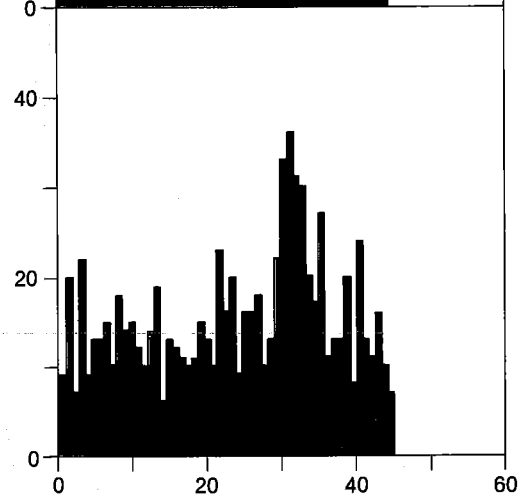
Optical bursts measured at Cerro Tololo Inter-American Observatory in the wavelength range of 3,100 to 5,500 angstroms. (Counts per second)



X-ray bursts measured by satellite in the energy range of 5 to 10 KeV. (Counts per 0.83 second)



X-ray bursts measured by satellite in the energy range of 2.5 to 5 KeV. (Counts per 0.83 second)



UT Time in Seconds
after 08:21:52 on
June 2, 1978

spectrographs, contained large numbers of strong, narrow absorption features in addition to the bright emission lines characteristic of lower dispersion quasar spectra. The redshift of these absorption systems was most often significantly less than that of the emission spectrum. The reasonable interpretation was that the quasar emission had encountered some intervening matter between the quasar and the observer on Earth. Serious objections were raised when the frequency of occurrences and multiplicity of the absorption redshifts were found to far exceed that predicted on the basis of such chance encounters.

In an attempt to resolve this and other questions related to the quasars' optical absorption lines, astronomers began to search for their counterpart radio absorption lines. The task has not been easy, and the new absorption line detected in 1331+17 is only the third positive detection at high redshift. The task is made significantly more difficult because the highly redshifted spectra place the expected lines far from the usual observing frequencies in the protected radio astronomy bands. Consequently, much of the work must be done at remote sites and after commercial transmissions have ended for the night. Instrumentation for the 1331+17 search included construction of a 12-meter-long line feed for the hydrogen line, which is normally found at 1,420 MHz but in this case redshifted to 511 MHz. The wide band tunable receiver was provided by the University of Pittsburgh.

In some ways 1331+17 was an unlikely candidate, being some ten times fainter at radio wavelengths than the preceding two successful absorption line sources. However, its redshift is sufficiently high to move the ultravi-

olet ground-state lines of neutral hydrogen into the visible, revealing an extraordinary amount of neutral hydrogen in the optical spectrum. Assuming a typical neutral hydrogen spin temperature of 100 degrees Kelvin, the scientists predicted an easily detectable 20-percent absorption dip. The line did not show up quite so easily; after 10 hours of integration in late March a 2-percent dip became clearly discernible. While extremely faint, the line was readily confirmed during a second observing run in May.

The detection was well worth the considerable effort invested, an effort which is better estimated when the negative results on another half-dozen objects in the same program are included. The astronomers calculate spin temperature of the gas about 1,000 degrees Kelvin, much higher than expected of material randomly encountered along the line of sight, but plausible if the absorbing gas is physically related, and affected by, the enormously luminous quasar itself.

This result is in itself astrophysically significant, and could only be determined for a quasar absorption line system of sufficiently high redshift that both the excitation ground state and the electron spin transition are simultaneously observable, a condition satisfied by neither of the previous two radio absorption line objects. But the findings have even greater import for our physical understanding of the early universe. This is because the measurement of the optical and radio redshifts for the same element permit stringent limits to be set on any variation in the ratio of the physical constants that determine the optical and radio wavelengths of the spectral lines. These limits can now be extended back to nearly two-thirds of the age of the

universe. It seems that physics in the era of quasar and galaxy formation was very much like our physics of today.

Solar Oscillations

According to a generally held view, the outer atmosphere of the Sun is heated by sound waves that are generated in the solar convection zone just below the solar surface. These sound waves are probably generated with a fairly broad range of periods. Because of a resonance in the solar convection zone, sound waves with periods near 5 minutes would build up to substantial amplitudes near the surface of the Sun. Most of this wave energy should be trapped in the resonant cavity of the convection zone, but some of it escapes and contributes to the heating of the chromosphere.

In order to test this idea, and to determine how much sound wave energy can escape, two scientists from the University of Colorado measured wave propagation in the layers just above the visible solar surface. The observations were made at Sacramento Peak Observatory's (SPO) Solar Vacuum Telescope using the echelle spectrograph and diode array. For several spectral lines that originate at different layers of the solar atmosphere, they monitored the Doppler shift and brightness of each line as functions of time. From these observations they deduced the velocity of phase propagation and the difference in phase between brightness and velocity.

Simultaneously with the SPO observations, similar ones were made from the Orbiting Solar Observatory launched by the National Aeronautics and Space Administration. A University of Colorado instrument on OSO-8 was used to observe time series profiles of the silicon II resonance line at 1,816 angstroms, while a spectrograph of the Laboratoire de Physique Stellaire et Planetaire was used to observe the core of the magnesium II resonance

Correlation. Simultaneous observations in June 1978 with the Cerro Tololo Inter-American Observatory's 1.5-meter telescope and the orbiting X-ray satellite SAS-3 produced these records of simultaneous "bursts" from a star in both the X-ray and optical regions of the spectrum. This first measured correlation of X-ray and optical bursts will help astronomers understand the physical cause of the heavily studied X-ray bursts.

line. The magnesium line is formed higher in the solar chromosphere than any other line that can be observed from ground-based telescopes. Thus the space observations were used to extend the range of the ground observations.

The experiment was carried out successfully during one week in February 1978. Preliminary analysis of the data showed that, indeed, the 5-minute oscillations propagate upward in the region just above the photosphere and that their amplitude decreases exponentially with heights as they give up energy to the atmosphere. An estimate of the wave flux available to heat the atmosphere has not yet been made, and further analysis of the data is planned to determine the amount of energy that is deposited in the atmosphere at each height. When this amount of energy is compared with the radiative and conductive energy losses from these regions it will be possible to decide whether the 5-minute oscillations contribute a substantial fraction of the energy to the upper layers of the Sun.

Youngest Star

Until November of 1977, an object familiarly known as BN (Becklin-Neugebauer) was surmised to be a collapsing prestellar object. But new discoveries with the Fourier Transform Spectrometer (FTS) at Kitt Peak National Observatory's 4-meter telescope indicate that BN is a full-fledged star, the youngest yet identified. Its status was confirmed by KPNO staff who developed the FTS and its infrared detectors, together with a visiting observer from the Massachusetts Institute of Technology. They estimate that BN may have reached stardom less than 2,000 years ago, well within recorded history.

The birth could not be observed optically, though, because BN is still deep within the thick cloud of gas and dust from which it has been formed. The discovery of such brand-new stars



Stellar birth. Kitt Peak National Observatory's 4-meter telescope was used in the identification last year of the youngest star ever identified—probably less than 2,000 years old.

had to wait for the development of infrared astronomy. In 1966, BN was found to be a bright infrared source, even though it is invisible to the eye. Because it is located in a large molecular cloud, the same cloud that includes the Orion Nebula and the Trapezium cluster of hot young stars, it was presumed to be a young object. Finding its exact stage of development, however, was a more complicated puzzle.

The clues to the puzzle's solution lay in the match between BN's observed properties and the predicted sequence of events in star formation. Before the birth of a star, a dense protostellar cloud of gas and dust undergoes a slow collapse by self-gravitation. As it collapses, its density increases and its gravitational energy is converted to heat. When the core density, pressure, and temperature become very large, the object is no longer a simple cloud; it has acquired all of the characteristics of a star. This era of birth is marked by

notable events. The nascent star begins a sweeping reorganization of the gas and dust surrounding it. The contraction stops; heat from the new star causes the cloud to start expanding outward. If the star is hot enough, its ultraviolet light will ionize the gas within an ever-increasing radius. Nuclear fusion begins to convert hydrogen to helium and to produce the energy that maintains the star in a stable configuration for most of its lifetime.

These insights were applied to BN. It was immediately known to be too young to have ionized a large volume of gas, because it does not show the radio emission that would be characteristic of such a region. The remaining question, then, was whether BN is still contracting or has reversed its collapse. In other words, is gas moving toward BN or away from it?

It was first discovered that BN is immediately surrounded by an ex-

panding shell of ionized hydrogen; this established that BN must be a star emitting the ultraviolet radiation needed to excite the gas. Second, it was discovered that the cooler cloud outside the ionized region is also expanding. Previous radio observations of this cloud had established its radius to be 1.5 trillion kilometers. By dividing this radius by the observed expansion speed of 850-million kilometers per second, KPNO observers were able to derive an age for BN of approximately 1,800 years. Although 1,800 years is a long time by human standards, BN is still in its "babyhood" as a star.

National Astronomy and Ionosphere Center

The National Astronomy and Ionosphere Center (NAIC) is centered around the world's largest radio/radar telescope, the 1,000-foot-diameter (305-meter) fixed spherical antenna, located near Arecibo, Puerto Rico. Operated by Cornell University under contract with NSF, NAIC is the Nation's premiere facility for advanced research in radio and radar astronomy and in ionospheric physics. Facilities and support services are available, free of charge, on an equal and competitive basis to visiting scientists from all over the world.

A major new facility for atmospheric research at the Arecibo Observatory—the high power, high frequency transmission facility—is presently under construction and should be ready for use during 1979. This facility—four transmitters delivering a total of 800 kilowatts to an array of log-periodic antennas—will be used principally for ionospheric heating experiments and the investigation of parametric instabilities and nonlinear processes in the ionospheric plasma.

Over the past several years, a major upgrading and scientific reorientation of the telescope and research programs have taken place. Most conspicuous have been the resurfacing of the reflec-

tor with a surface expected ultimately to be more than 10 times as accurate (smoother) than the old reflector and the installation of a high power S-band radar system with a sensitivity more than 1,000 times greater than that of the old UHF system. Less obvious have been the construction of high quality receiving systems for radio frequencies not previously usable with the old reflector and the installation of new data acquisition and processing equipment. These have been accompanied by enormous progress in developing new observational techniques and computer programs especially suited for general visitor use and by a steady increase in visitor use of the Arecibo telescope for high quality research. In fiscal year 1978, 35 percent more visitors used the facilities than during the previous year. Of the total observing time available in this period, more than 73 percent was used by visiting researchers. The number of visitors has more than tripled in 3 years and almost quadrupled over the past 4 years.

Kitt Peak National Observatory

Kitt Peak National Observatory (KPNO) is operated by the Association of Universities for Research in Astronomy, Inc., under contract with NSF, from headquarters in Tucson, Ariz. The observatory's basic programs support the operation of 13 telescopes at a mountaintop site 90 kilometers (50 miles) from Tucson. Many of the telescopes, including the Mayall 4-meter telescope, are used for daytime infrared observations in addition to a wide variety of nighttime observations. The McMath complex of three telescopes, designed primarily for solar observations, is used frequently for nighttime studies of planets and stars.

In October 1978 Geoffrey Burbidge became the new director of KPNO, filling the position left vacant by the retirement of Leo Goldberg in October 1977. Burbidge comes to KPNO from

the University of California, San Diego, where he has been a professor of physics since 1962.

As a national center, KPNO facilities were used by 363 visitors, including 73 students, from 70 domestic and 19 foreign institutions during fiscal year 1978. Telescope time is divided so that 60 percent is assigned to visitors and 40 percent to scientists on the KPNO staff. Visiting astronomers undertake programs encompassing the entire field of astronomy—from cosmology to solar physics. KPNO's success depends on the creative interaction between visiting and staff astronomers. In addition to carrying out observatory research programs, the resident staff of astronomers, engineers, and various support personnel contribute to programs designed to ensure that KPNO is meeting the needs of the visiting astronomers. This responsibility includes planning and developing new instruments and data reduction techniques.

An integral part of the KPNO instrumentation development program is to apply the most advanced technology to astronomical instrumentation. The observatory activities include development of two-dimensional optical and infrared detectors, large diffraction gratings, auxiliary instruments for existing telescopes, and engineering designs for telescopes of the future.

Several instruments brought into use during fiscal year 1978 underscore the recent emphasis on modern detectors. A new "video camera" makes use of a vidicon tube for photometric observations of extremely faint two-dimensional star fields. In the "high-gain video spectrometer" a digital detector multiplies the speed of photographic spectroscopy by more than an order of magnitude. The "CID camera" incorporates a silicon diode detector array for use with several instruments at the McMath telescope. These recent projects could not have been realized without the parallel development of computer hardware and software. One

of KPNO's priorities is to make these research tools of current astronomy, which were unheard of 10 years ago, accessible to the entire astronomical community.

Cerro Tololo Inter-American Observatory

Cerro Tololo Inter-American Observatory (CTIO) is operated by the Association of Universities for Research in Astronomy, Inc., under contract with NSF. Located on the Chilean slopes of the Andean cordillera, approximately 480 kilometers (300 miles) north of Santiago, CTIO is a center for research in ground-based optical astronomy in the Southern Hemisphere. The dark sky and stable air mass of the mountaintop site some 64 kilometers (40 miles) inland from the coastal city of La Serena provide near ideal observing conditions for the eight telescopes there. These include a 4-meter reflector that is the twin of the KPNO Mayall telescope.

In fiscal year 1978, CTIO facilities were used by 129 visiting scientists, including 14 students, from 45 U.S. and 18 foreign institutions. At least 60 percent of the available observing time on the telescopes is assigned to these visiting astronomers, with the remainder being assigned to the CTIO scientific staff.

The research programs carried out at CTIO emphasize unique Southern Hemisphere objects such as the Magellanic Clouds, nearest neighbor galaxies to our own Milky Way system; X-ray sources, a new class of celestial objects lacking optical identification; globular star clusters, probably the first gravitationally bound mass concentrations to form; and Baade's "window," a region of low obscuration toward the dust-shrouded center of the Milky Way. The galactic center itself, overhead at CTIO, is also of great interest because of its dense concentration of gas and short-lived bright stars.

CTIO has evolved as an organization that makes particular use of the resi-

dent scientific staff in developing observational capabilities. Each scientific program or project area and scientifically oriented observatory activity has a staff astronomer or support scientist designated as scientific adviser. CTIO also has a nonresident scientific program which enables the observatory director to offer temporary appointments to scientists from other institutions. These people conduct their research using the CTIO facilities and interact with both the resident staff and visiting scientists for the mutual benefit of all concerned. Appointment periods may range from a few weeks to several months, depending on the amount of time the visitors can be absent from their home institutions and on the availability of housing in La Serena.

Recent major accomplishments by the CTIO staff resulting from this emphasis have been the consolidation of the Cerro Tololo data processing computers in one location for access by a single, shared network; installation of new vidicon detectors and related image processing equipment; and the development of infrared capabilities.

National Radio Astronomy Observatory

The National Radio Astronomy Observatory (NRAO), operated by Associated Universities, Inc., has its headquarters in Charlottesville, Va. Observing stations are located in the radio quiet zone at Green Bank, W.Va., at the Very Large Array (VLA) site near Socorro, N.Mex., and, for millimeter-wave observations, on Kitt Peak near Tucson, Ariz.

During the past year at the VLA, which is nearing completion, the level of operation for scientific research increased from 39 to 55 percent. The number of antennas in use at one time has increased from 7 to 12, and by the end of 1978 the 20th antenna of the required 28 was planned to be accepted from the manufacturer in accordance

with the original delivery schedule. Work continues on several antennas to install subreflectors, feeds, receivers, and cryogenic refrigerators. The number of interferometer base lines has been increased from 21 to 66. The longest base line (distance between two antennas) available increased from 5.2 to 11.5 kilometers, allowing an angular resolution of better than an arc-second. Under a contract awarded for the Phase V trackage construction, 21.9 kilometers of double wye track will be laid, completing over half the required VLA track. The final 21 antenna foundations will also be completed under this contract. The completion of several new buildings has permitted occupation of the second visiting scientists quarters, a library-office building, a garage, and the addition to the cryogenics facility.

At the Green Bank site, a Mod Comp II-25 computer was installed at the 91-meter (300-foot) telescope to allow data analysis to proceed simultaneously with observations. The 18 to 26.5 GHz (gigahertz) maser receiver developed at the NASA-sponsored Jet Propulsion Laboratory has been used extensively on the 42-meter (140-foot) telescope and performs extremely well in every respect. Additional K-band masers have now been built at Green Bank and will be used to improve receiver performance on all telescopes in the 1- to 26-GHz range. The Mark III Very Long Baseline recording system developed jointly with NASA has been successfully tested on an experiment using the NRAO 42-meter telescope and the Haystack antenna. A second system is now being built for use at other sites. A deformable subreflector has also been built on the 42-meter telescope to improve efficiency at short wavelengths. Initial results show that the astigmatism caused by antenna deflections can be corrected.

At the Kitt Peak site, the 36-foot (11-meter) telescope has been provided with a sunscreen to protect it from solar heating and to allow daytime observations of galactic objects.

NRAO has continued its development of receivers for the wavelength region of 1 to 3 millimeters. A cooled receiver with a harmonically pumped mixer will be in regular use next year for wavelengths near 1.5 millimeters. Work is now beginning on a cooled mixer for the 2-millimeter region.

David Heeschen ended his 15-year directorship of NRAO on September 30, 1978, and returned to scientific research at NRAO. Morton Roberts, a long-time senior scientist at NRAO, succeeds him.

In the past year 314 visiting scientists, representing 90 institutions, used the NRAO telescopes. The 36-foot millimeter-wave telescope continues to be heavily oversubscribed. While the telescope is limited in both sensitivity and resolution, investigators successfully detected the long-sought nitrogen oxide molecule NO, and the carbon chain radical C₄H.

Sacramento Peak Observatory

Sacramento Peak Observatory (SPO), operated under contract with the NSF by the Association of Universities for Research in Astronomy, Inc., offers unique instruments and facilities for advanced research in solar physics and related disciplines. The SPO facilities are located at an elevation of 2,760 meters (9,055 feet) in the Sacramento mountains of south-central New Mexico. The facilities are available to all qualified scientists; telescope time is allotted on the basis of scientific proposals, which are reviewed by external referees. Approximately half of the available time is now being allocated to nonstaff members.

On June 19, 1978, SPO began operation of a 1.2-meter (48-inch) Newtonian reflector at Cloudcroft, N.Mex., under the terms of a 1-year agreement between NSF and the U.S. Air Force. The reflector was used previously as a satellite-tracking telescope. It has a three-axis mount, very fast slew rates, and precise absolute pointing con-

trolled by an IBM 1800 computer. SPO will monitor the brightness of several planetary satellites and asteroids in order to search for solar-induced variations in brightness, especially short-term fluctuations. In addition to this primary purpose, SPO will offer a limited amount of observing time to the general astronomical community for synoptic stellar photometry.

During the past year a new fast microphotometer has been put into service for the use of SPO visitors. The microphotometer is designed to do master scans of both standard 35- and 70-millimeter frames. Controls allow any portion of the frame to be digitized, with up to 7,500 data points

digitized each second. The instrument is 20 times faster than the old microphotometer at SPO.

A prototype of a new instrument for measuring small systematic velocities on the Sun is being developed at SPO. The instrument, designed as a Fourier tachometer, employs a scanning Michelson interferometer with a local wavelength reference. The sensitivity of the instrument has not been determined as yet but it has been designed to measure velocities on the Sun the order of 10 meters per second and less. The instrument will be used to measure the slow circulation of the solar atmosphere, differential rotation, and global pulsations.

Atmospheric Sciences

NSF's atmospheric sciences program supports research on a wide range of subjects—the physics, chemistry, and dynamics of the Earth's upper and lower atmosphere; the relationship of physical processes in the troposphere and stratosphere to the general circulation of the atmosphere and the physical basis of climate; climate processes and variations; and smaller scale, shorter term phenomena leading to greater knowledge of weather. All these studies complement the mission-oriented research carried out by other agencies.

The Foundation also supports the development and operation of the National Center for Atmospheric Research (NCAR), a national research center devoted to large-scale atmospheric research projects conducted in cooperation with universities and other organizations. NCAR maintains major facilities for computing and for ground-based and aircraft observations. NSF also supports the participation by the U.S. scientific community in international scientific research endeavors such as the Global Atmos-

pheric Research Program (GARP) and the International Magnetospheric Study (IMS).

Basic research support is provided in the following areas. The aeronomy program funds laboratory, theoretical, and field studies involving processes of ionization, recombination, chemical reaction, photoemission, and transport. The atmospheric chemistry program supports laboratory, field, and modeling efforts for both the troposphere and stratosphere. The experimental meteorology and weather modification program supports field-oriented research on weather, including potential applications to weather modification; the meteorology effort includes all aspects of dynamical and physical meteorology. The solar terrestrial research program is concerned with studies of the highest extent of the Earth's atmosphere and the near-Earth space environment, interplanetary medium, and the solar atmosphere. The GARP program supports research in universities, with current emphasis on completing the analysis of data from the GARP Atlantic Tropical

Experiment and carrying out the Monsoon Experiment (MONEX). The climate dynamics program supports studies of climate data assembly and analysis, simulation and prediction of climate, and climate change impact assessment.

Atmospheric Chemistry

Measurements of the distribution of trace gases and aerosols in the troposphere are a major objective of research in atmospheric chemistry. These measurements are now providing the first data in which the concentrations of many atmospheric constituents are measured simultaneously with the solar flux that drives photochemical reactions among them and with the meteorological parameters important in determining the global distribution of trace species in the atmosphere.

The 1977 *Annual Report* discussed first-year results from Project GAMETAG (Global Atmospheric Measurements Experiment on Trace Aerosols and Gases), a collaborative effort among scientists from six universities, the NCAR research staff, and private

industry. Douglas D. Davis of the Georgia Institute of Technology is the project director. In 1978 a second series of aircraft experiments was conducted, again using the NCAR Electra research aircraft. In 1977 and 1978 the flights covered more than 45,000 miles over the latitude range 70° N. to 57° S. and between 95° W. and 165° E. longitude.

The GAMETAG flights have produced a remarkable data base on the distribution of trace gases and aerosols in the troposphere. For many species they yielded the first measurements over a large geographical area and over a range of altitudes. Ultraviolet solar flux, relative humidity, temperature, pressure, and wind velocity measurements were made simultaneously with the chemical measurements.

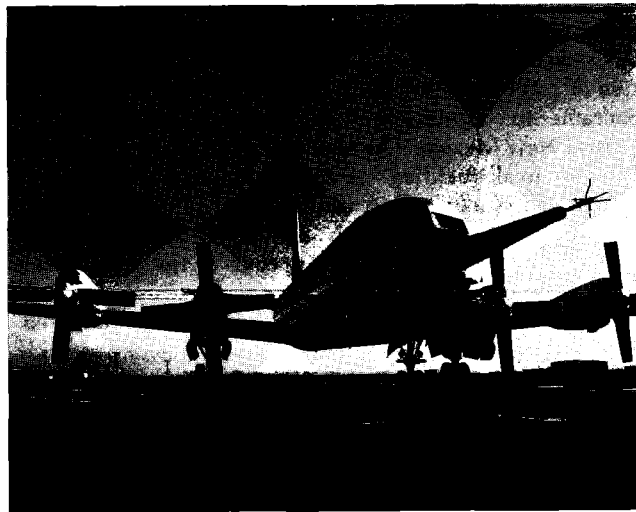
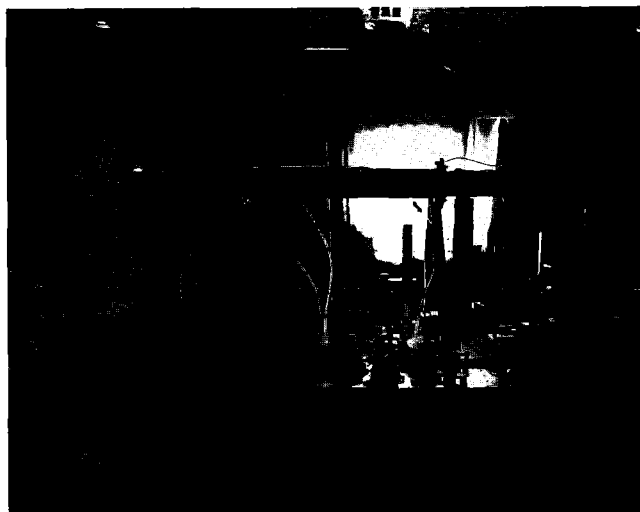
The detailed results of this project are an important first step in the accumulation of knowledge about the natural troposphere; this knowledge will lead to an understanding of natural and anthropogenic sources and sinks of gases and aerosols in the atmosphere, their transport processes, and the photochemical interactions among them. Such knowledge of the atmosphere will substantially improve

our ability to predict the effects on the quality of the atmospheric environment of freon compounds, nitrogen and sulfur oxides, and carbonaceous combustion products.

Prediction of Aurora

One of the most important and visible manifestations of the interaction between the Earth's and the Sun's atmosphere are the aurora borealis, or "northern lights." Notwithstanding their beauty, the aurora borealis cause problems by disturbing the polar ionosphere and disrupting radio communications and causing navigational difficulties. Radar facilities and satellite performance are also affected by the electromagnetic disturbances. When such disturbances are very intense, they even induce spurious currents in powerline systems, particularly in Canada and the northern United States, where violent auroral displays occur.

However, some of the operational problems of such facilities could be avoided if a reliable forecast could be issued. Communication centers would then have enough time to plan for



Project GAMETAG. This laser-induced fluorescence detector (left) aboard NCAR's Electra research aircraft (right) measures concentrations of the chemical species OH, which is a key to the atmospheric lifetimes of many trace gases and which interconnect several photochemical cycles.

blackouts and program around the disruptions that will be caused by auroral activity. It now appears that scientists at the University of Alaska's Geophysical Institute will soon be able to forecast accurately when the aurora will occur in the polar region and how intense they will be. The Alaska research team's work builds on 20 years of study of the Earth's electromagnetic environment by space physicists in the United States and other countries.

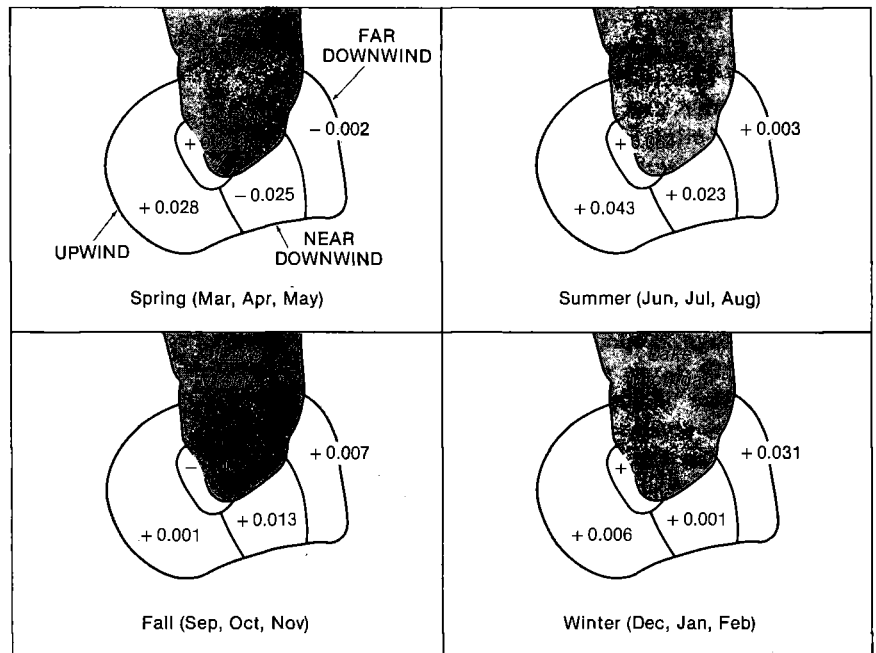
Scientists now know that the aurora are gigantic electrical discharge phenomena—like huge neon signs—from 60 to 300 miles high in the polar atmosphere. This discharge is driven by a powerful natural generator in the sky, providing as much as 100 billion watts—more than 100 times the total annual U.S. electric power consumption. This celestial generator, the magnetosphere, is formed by the interaction of the solar wind, a hot gas streaming from the Sun, and the Earth's magnetic field.

It has long been known that solar and auroral activity are generally correlated. As a result of this research we now understand the basic physics that controls the efficiency of the generator. Thus, the intensity of auroral activity is controlled by a combination of three factors: the solar wind's speed, and both the magnitude and orientation of the magnetic field carried by the solar wind.

On the basis of these results it is possible that the third International Sun-Earth Explorer satellite, now in position in the solar wind, will send back data enabling accurate forecasting of both occurrence and intensity of major auroral activities about 2 hours before they start.

Urban Effects on Weather

Recent studies of seasonal and annual precipitation around the southern end of Lake Michigan for 1931-76 have indicated the presence of apparent local urban anomalies in precipitation in



Urban effects. Trends of regional precipitation from 1931 to 1976 for the Chicago area and three regions around it show how actual precipitation differed from what would be expected. The largest anomalies occurred in winter and summer; net annual regional increase in precipitation as a result of the urban center is calculated to be about 2.5 inches.

Chicago. These occur primarily in the summer season (being greatest in the south-central part of the city) and represent about a 15-percent increase in that season over the past 46 years. A winter increase of about 10 percent is also evident; the trends in the city during the spring and fall transition seasons are so near the climatologically expected value as to be considered of no consequence. The net precipitation change over the 46-year period reveals an increase of 2.5 inches in the annual rate in the Chicago urban area. In the near downwind area, the urban-industrial influences appear to have diminished precipitation in the colder months of the year and enhanced them in the warmer months.

In general, consideration of these trend patterns supports the concept of local, urban-related increases in precipitation over Chicago, particularly in summer and winter. It also appears likely that local urban-industrial ef-

fects produce an increase beyond the city in the warmer months and a decrease in the colder months, a fact not found in previous urban investigations of the Chicago area.

Average rainfall patterns, based on heavier short duration (1 day or less) rainstorms during 1949-74 in the Chicago area, strongly indicate localized influences on the precipitation distribution. Heaviest storm rainfall occurs over the city center when the more well organized (squall line and cold front) heavy precipitation systems occur, but not when unorganized systems produce regionally heavy rains. Influences appear greatest when a squall line produces the rain. When storm systems move from the northwest, a secondary rainfall high is found in northwestern Indiana, indicating that urban effects may have extended well beyond the city center.

The results of this study are in close agreement with the results from the

recent METROMEX (Metropolitan Meteorological Experiment) studies for St. Louis. That is, the urban influence on rainfall is greatest when well organized synoptic conditions are producing heavy precipitation. The Chicago area project is being directed by Stanley Chagnon of the University of Illinois, who was also involved in the earlier St. Louis research. The appearance of an average maximum over the center of Chicago, as opposed to east of the center of St. Louis, may be due to the greater size of Chicago and the longer fetch for storms moving across the metropolitan area. These results suggest the potential for transferability of the METROMEX results about rainfall distribution and synoptic weather types.

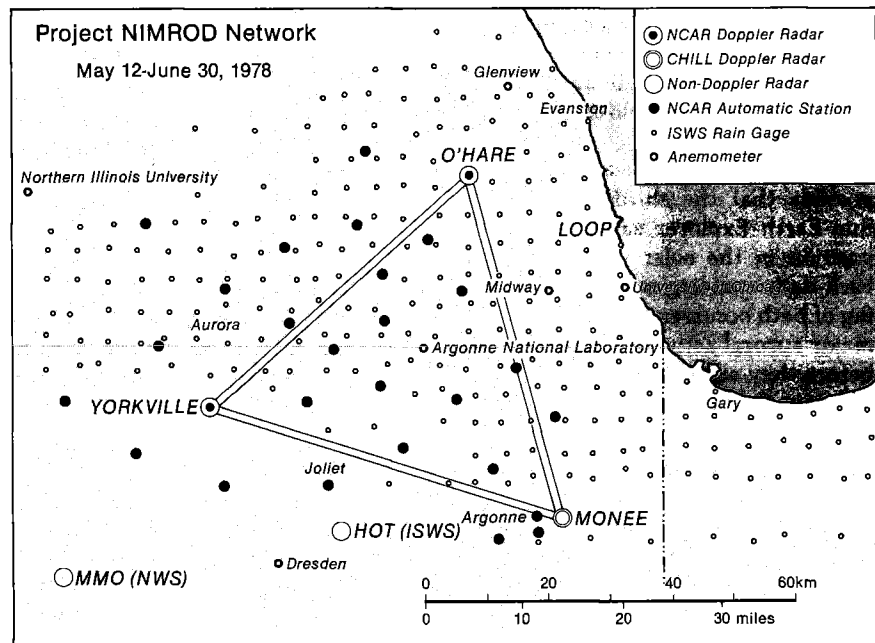
Downbursts from Thunderstorms

At 4:05 p.m. on June 24, 1975, Eastern Airlines Flight 66, coming in for a landing, hit the approach lights 730 meters short of the runway at John F. Kennedy International Airport in New York City. A total of 122 persons were killed and 12 others were injured. The cause was attributed to severe wind shear—an abrupt change in direction and speed—that the plane encountered. A meteorological investigation of the accident by Ted Fujita of the University of Chicago revealed that the fatal wind shear was caused by an avalanche of air that descended from a thunderstorm just to the north of the airport.

Such a storm is referred to as a "downburst." An avalanche of descending air bursts out as it hits the ground surface. In 1976 Fujita, working on the assumption that strong downbursts result in permanent damage to corn, trees, and possibly structures, began a large-scale search for downburst damage. He and his associates found and photographed effects of strong winds from downburst centers at various locations—such as corn



Dangerous weather. A downburst, a local avalanche of rapidly descending air from a thunderstorm, was implicated in the tragic 1975 crash of an airliner at New York's Kennedy Airport. Subsequent research to assess the incidence of downbursts showed that they leave characteristic damage to vegetation, as in this wooded area (above) in northern Wisconsin following a July 4, 1977, downburst. A subsequent field experiment, Project NIMROD (below), in mid-1978 observed at least ten downbursts in the Chicago area in a 2-month period.



fields in Illinois and Wisconsin forests. Some downbursts were only 1 to 2 miles across with an estimated active life of less than 5 minutes.

As a consequence of that successful research, three agencies—NSF, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration—supported a fact-finding experiment on downburst phenomena over the western suburbs of Chicago in May and June 1978 under the name of Project NIMROD (Northern Illinois Meteorological Research on Downburst). One of NIMROD's major objectives is to determine meteorological characteristics of downbursts in an attempt to devise both methods and equipment capable of detecting downbursts in and around the major airports and major metropolitan areas.

At least ten downbursts were successfully documented during the experiment by Doppler radars and the automatic surface observation stations, operated by the National Center for Atmospheric Research, while one of the SMS weather satellites was photographing the network area. Some of these downbursts reached speeds of 60 miles per hour and lasted for several minutes. NIMROD data, which are being investigated, revealed that there were more downbursts in thunderstorm areas than expected. By virtue of their small dimensions (1 to 10 miles) and short life (1 to 30 minutes), most downbursts had previously escaped detection by ordinary weather radar. For instance, a downburst on May 29, 1978, occurring 8 miles southwest of Chicago's O'Hare Airport, would not have been detected if there were no NIMROD network.

Climate Dynamics

On time scales of seasons or less, a large part of the variability of climate can be caused by random interactions between the atmosphere and oceans. But a long-term fundamental problem

in climate theory is to determine how much of climate variability is due to random, as opposed to nonrandom, causes.

Significant progress on this problem is being made as a result of recent work by Klaus Hasselmann and coworkers at the Max Planck Institute, who constructed a quantitative stochastic climate model that predicts key statistical properties of the paleoclimatic, or long-term record. U.S. scientists have been quick to recognize the importance of this theoretical breakthrough in climate research and have devised experiments to test Hasselmann's model.

Initial results by John Imbrie and his colleagues at Brown University, using paleoclimatic data from deep sea cores, show significant agreement between observed and predicted time series of climatic data. Imbrie is studying the change in abundance patterns in marine organisms preserved in ocean cores as a sensor of past sea surface temperatures. Analysis of cores from the Santa Barbara Basin off the coast of California, interpreted in terms of past temperatures, has revealed a unique paleoclimatic record. These ocean cores are thickly laminated and can be resolved to intervals of every 50 years for the past 7,000 years. When the reconstructed paleotemperature record for this core is analyzed by spectral statistical methods, the randomly caused part of the temperature variability can be identified and mathematically described. It is in this way that the observed paleoclimatic data conform to the model predicted by the stochastic theory. The results of these studies will eventually greatly improve the feasibility of climatic forecasts.

Continued progress requires better understanding of the complicated statistical procedures involved in spectral analysis. To this end, a major workshop on statistical modeling and spectral analysis was organized in fiscal year 1978 by the National Center for Atmospheric Research. Leading experts in statistics, climate modeling,

and paleoclimatology met to exchange ideas on the problem of climatic variability and to provide scientific guidance for future studies.

Global Atmospheric Research Program

Ocean-Atmosphere Interaction During the Monsoon

Since 1975 NSF has supported oceanographic research in the Arabian Sea as a precursor to the oceanographic component of the Monsoon Experiment (MONEX), the field phase of which will occur in fiscal year 1979. MONEX is a subprogram of the international Global Atmospheric Research Program (GARP). A major objective of MONEX is to understand the complex interactions between the southwest monsoon winds and the mixed upper layers of the Arabian Sea.

The Arabian Sea is of interest scientifically because it is the only large body of water in the Northern Hemisphere that cools during the monsoon period from May through July, a period of intense net solar heating in that region. Since the Arabian Sea lacks a polar region to remove the excess heat, an intriguing question is, "Where does the heat surplus go?" The disposition of this thermal energy from the Arabian Sea has been shown to be important for the development of monsoonal rains over India. Thus, a MONEX objective is to try to understand how the Arabian Sea and the southwest monsoon winds interact to produce the observed cooling and monsoon rain.

The cooling of the surface layers appears to be due to a combination of cold water that is brought to the surface along the East African and Arabian coasts, deep mixing of the surface layers, and the direct cooling at the surface through evaporation. Some clarification of these complex processes was gained for the first time during this past year by results from a project directed by Walter Duing of the University of Miami. Duing has been

continuously monitoring the Somali Current, which runs along the western boundary of the Arabian Sea and is strongly affected by the monsoon wind system. Despite the importance of this current to seafarers for nearly 2,000 years, until recently there existed no single continuous time series from a modern recording current meter.

A first long-term current meter record obtained by Duing from the region indicates that the classical picture of a direct oceanic response to the forcing of the wind may be greatly oversimplified. It turns out that some of the key features of the record are not related to fluctuations of the wind field, but are more likely related to large-scale oceanic eddies propagating northward along the coast. Nevertheless, these measurements have demonstrated that the local winds greatly affect the seasonal variation of the Somali Current. Thus, 1 month before the large-scale onset of the southwest monsoon, the Somali Current direction reverses to a northeastward direction.

The implications of these findings are important to the problem of predicting the behavior of the southwest monsoon. Genuine improvements can occur only when the interactions between the ocean and atmosphere in that region are understood clearly enough for successful modeling and simulation. It is anticipated that the observations obtained during MONEX will further clarify the controlling mechanisms of these interactions.

New Potential Indicator of Hurricane Development

William Gray of Colorado State University has been analyzing data collected in the eastern tropical Atlantic region in the summer of 1974 during the GARP Atlantic Tropical Experiment (GATE), a regional project of the Global Atmospheric Research Program. He has been examining the detailed structure of "cloud clusters"—intense tropical storm regions of or-

ganized, deep, vertically developing systems. While these cloud clusters occur frequently, only a few develop into hurricanes. One of his objectives is to classify the clusters into those that develop and those that do not develop into hurricanes.

Atmospheric data for the tropics, except for that collected during organized experiments like GATE, are scarce. For that reason, Gray expanded his available data base by combining the GATE data with 10 years of storm data that he has analyzed from both the tropical Atlantic and Pacific Oceans. His analysis technique permitted him to combine and sort the extensive data base into "typical cloud clusters" that develop into hurricanes and those that do not. Gray computed a measure of the horizontal rotation for various levels between 0.5 and 12 kilometers in the tropical atmosphere in which the cluster was imbedded. His analysis showed large differences between the vertical variation of this rotation measure for the two cases. In fact, the vertical variation of the rotation in the region of developing storms was two to four times as large as in the environment of nondeveloping clusters. No other parameters that Gray analyzed appear to be significantly different in the two cases.

Gray concludes that the strongest influence on hurricane development is the structure of the rotational character of the tropical environment in which the cluster is moving. Because large-scale rotation is a quantity that is routinely forecast in numerical models, Gray's finding has the potential of improving the prediction of hurricane development.

National Center for Atmospheric Research

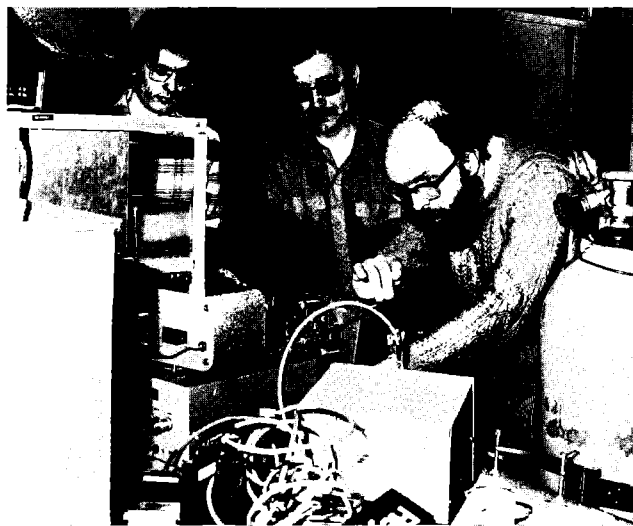
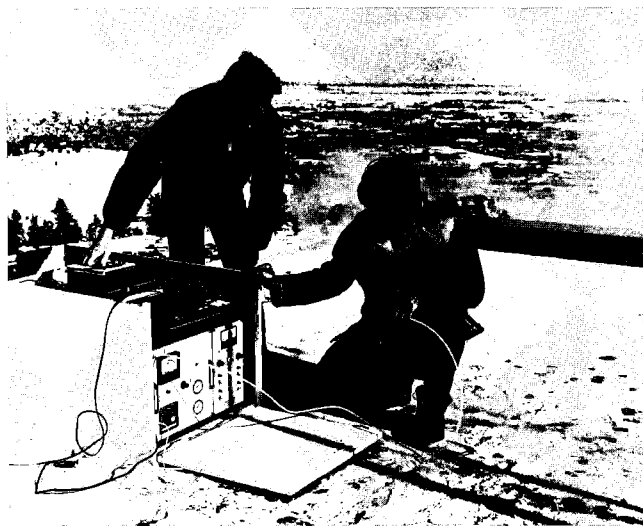
The National Center for Atmospheric Research (NCAR) and the National Scientific Balloon Facility are operated under contract with NSF by the University Corporation for At-

mospheric Research, a consortium of 43 U.S. and 2 Canadian universities. NCAR's research mission centers on selected problems in atmospheric science of national and international importance and scope, and the development and provision to users of unique research services and facilities.

Within the context of these missions, five general research objectives guide the planning of specific NCAR programs: (1) better weather prediction, (2) better understanding of climatic trends and their causes, (3) increased knowledge about severe storms to improve prediction and warning and permit evaluation of possibilities for modification, (4) improved understanding of solar processes and their influences on the interplanetary medium, and (5) trends in and influences on air quality.

Research during the past year included the "first echo" studies, which deal with the initial development of precipitation in thunderstorms as revealed by the appearance of radar echoes. These studies are necessary to deduce the growth histories—the microphysical events and the trajectories—of the first precipitation particles that form in convective cloud turrets.

Another important project, concerning the effects of thermal pollution, was a computer simulation of the heat input of a projected U.S. East Coast "megalopolis," a giant urban area releasing heat to the atmosphere at the same rate as Manhattan Island. In the simulation, precipitation increased over the megalopolis in general, but since the evaporation rate also increased, soil moisture content on the western edge of the megalopolis tended to decrease, indicating that a supercity of the future may induce greater aridity in nearby regions. The regional effects did not appear to exert any influence beyond the region or in other parts of the Northern Hemisphere, but the scientists caution that further investigation is required to delineate all the possible climatic im-



Atmospheric chemistry. Scientists from the University of Michigan and the National Center for Atmospheric Research build and test equipment at NCAR's Mesa Laboratory in Boulder, Colorado, for use in studying the solar photolysis of nitrogen oxides in the troposphere.

pacts of such thermal pollution.

In research on atmospheric chemistry, scientists from the University of Michigan, working in collaboration with NCAR scientists, found that the equilibrium among nitrogen dioxide, ozone, and nitric oxide in the troposphere, long thought to exist, may not in fact exist. If true, this would indicate the activity of other chemical species previously thought unimportant and would require a rethinking of the sequences of reactions now used in models of tropospheric chemistry.

Other NCAR and NCAR/university research programs during the past year were concerned with understanding convective storms and other severe weather phenomena, with the physics of the upper atmosphere, and with solar physics. A particularly important area of solar research has been solar

variability, since that has implications for the terrestrial climate.

NCAR facilities made available to the atmospheric science community include its computing facility, with one of the world's largest and fastest computers, a CRAY-1, and associated equipment helping hundreds of scientists yearly in both modeling and data analysis. NCAR also operates a fleet of four instrumented aircraft and supplies large radars, automated data-gathering systems, and technical expertise to groups doing field experiments. The National Scientific Balloon Facility, located in Palestine, Tex., supplies launch crews and engineering support to scientists whose experiments are flown on large, high-altitude balloons. These experiments are in infrared or high energy astronomy, atmospheric science, and other fields.

resources wisely for our benefit and for our very survival. Research in the earth sciences is predicated on the principle that the more we know about our spaceship the better we utilize it without courting its and our own extinction.

In view of the great dependence of modern society on natural resources, one might expect that the major problems of the structure and composition of the Earth would long ago have been solved, and that present work would be mostly concerned with the details of how such things as the concentration of ore deposits, the accumulation of petroleum, and the movements of ground water fit into the general laws. In fact, this is not true. Despite the great amount of excellent work that has been done and the tremendous amount of knowledge that has been accumulated, we do not really know why the continents are where they are, how they originated, how mountain ranges are formed, how earthquakes are related to volcanoes, or even whether the Earth is heating and expanding or cooling and contracting.

But we are making progress, and some of it is spectacular. In the past

Earth Sciences

The Earth is a spaceship, limited in size and limited in its total resources. For the foreseeable future it is the only

possible habitat for the billions of human beings who ride it. We must, therefore, both conserve and utilize its

equivalence, the cornerstone of the theory of general relativity.

Ocean Sediment Coring Program

The Deep Sea Drilling Project (DSDP) has been funded by NSF since 1966 as the major part of the ocean sediment coring program. The fundamental objective of the DSDP, the exploration of the Earth's surface beneath the ocean, is met initially by drilling and coring sediments and rocks in the ocean floor. The University of California manages the project for the Foundation, and Scripps Institution of Oceanography is responsible for the scientific program. Global Marine, Inc., does the actual drilling and coring operations using its drilling ship *Glomar Challenger*.

Operations for DSDP commenced in August 1968, and as of mid-September 1978, 705 holes had been drilled by the *Challenger* at 465 sites in a series of 61

2-month cruises (legs). These legs have cored every major ocean basin except the Arctic. From the beginning, the world scientific community has displayed tremendous interest and cooperation with respect to the project. Many scientists from outside the United States have made contributions both as participants aboard the *Challenger* or as members of the several advisory panels.

The International Phase of Ocean Drilling (IPOD), begun in October 1975, has furthered this spirit of cooperation, and IPOD presently receives \$1 million annually from each of five foreign countries, including the Soviet Union, Federal Republic of Germany, United Kingdom, France, and Japan, for its operational costs.

In fiscal year 1978 the *Challenger* operated in the area of the Western Pacific Ocean. Intensive drilling was done in areas with historically active tectonic signatures, of particularly old ocean sediment, and in sediments far

from the influence of continental masses.

Legs 56 and 57 in late 1977 involved the drilling of a transect of the Japan Trench. Results of that drilling showed that there is much more depression of the ocean crust there than had been previously envisioned. Evidence suggests that during early Cenozoic time (some 50 million years ago), Honshu Island projected much further eastward into the Pacific than at present. Five sites drilled in the northern Philippine Sea contributed to a better understanding of the complex tectonic history of this area, where earlier geophysical mapping had indicated a simple origin of symmetrical spreading.

Legs 59 and 60 comprised an east-west transect across a series of ridges and trenches bounded on the east by the Mariana Trench. This transect represents the culmination of years of planning to examine in detail, with closely spaced drill sites, a tectonically



South Pacific drill cores. Leg 60 of the Deep Sea Drilling Project retrieved samples of rocks from the region where the Pacific and Asiatic plates collide. Left—Geologists Anatoly Sharaskin of the U.S.S.R. Academy of Sciences and Patricia Fryer of the Hawaii Institute of Geophysics check the color of recovered material aboard the Drilling Vessel *Glomar Challenger*. Right—Also aboard ship, Timothy Francis of the Institute of Oceanographic Sciences in Reading, England, and Seiya Uyeda of Tokyo's Earthquake Research Institute measure the dissipation of heat in drill core material recovered near the Mariana Trench.

active ocean margin at its colliding border. The results of this drilling gave evidence that, at this point of collision between the Pacific and Asiatic plates, part of the overriding plate is being subducted or carried under rather than, as had been suspected, being plastered onto the adjacent subducting slab.

Leg 61 was designed as a single hole, multiple-entry site into older Mesozoic rocks in the Nauru Basin north of the Caroline Islands. Older sediments away from the influence of adjacent continental masses were sought here in order to examine a particularly intriguing interval in the Mid-Cretaceous (about 65 million years ago). The distinctive black shales of this sequence, which occur in several places in other ocean basins of the world, may represent a worldwide period of relatively low oxygen in the deep ocean basins. Such an event would have considerable bearing on present ideas of the origin and accumulation of hydrocarbons in the deep ocean.

Advances in High-Pressure Research

High-pressure research made a significant advance in the past year at the Geophysical Laboratory of the Carnegie Institution of Washington with the attainment of a static pressure of 1.7 megabars in a diamond anvil pressure cell. This pressure, equivalent to that encountered in the Earth's lower mantle, had previously been attained only during the passage of explosive shock waves through experimental materials. As a result, it is now possible to directly observe phase chemistry of minerals at conditions of pressure and temperature approaching those at the boundary between the Earth's mantle and core.

The experimental technique consists of placing a sample between two precisely aligned cut diamonds which are pressed together. The 1.7-megabar pressure attained may represent a

practical maximum for this technique, since one of the diamonds actually underwent plastic flow during one of the experiments. This phenomenon—flow in a diamond—had not been observed before.

Because the diamond anvils are transparent, the samples under pressure can be observed visually and also can be heated to temperatures as high as 1,500 degrees C by laser beams. In addition, samples may be studied by X-ray diffraction and a variety of spectroscopic techniques, allowing determination of crystal structures and various chemical and physical properties.

Glaciation on Mauna Kea

Worldwide fluctuations of temperature during the Pleistocene Epoch (the most recent period of geologic time) resulted in episodes of continental and alpine glaciation and changes in the temperature, volume, and characteristics of the world's oceans. Estimates of the duration and absolute amounts of cooling during the glacial cycles have been based on dating of glacial deposits, calculations of variations in snow lines at various places where glacial deposits are found, and determinations of oxygen isotope variations in glaciers and in fossil marine organisms from deep-sea cores.

An unusually good record of multiple Late Pleistocene glaciation is found near the summit of Mauna Kea on the island of Hawaii. Geological studies by scientists from the University of Washington show that icecaps occupied the summit of Mauna Kea four times during the past 250,000 years. Glacial moraines and outwash deposits are interbedded with lava flows and layers of pyroclastic material (tephra) erupted during the last phases of the volcanic activity that built the mountain and that ended about 4,500 years ago.

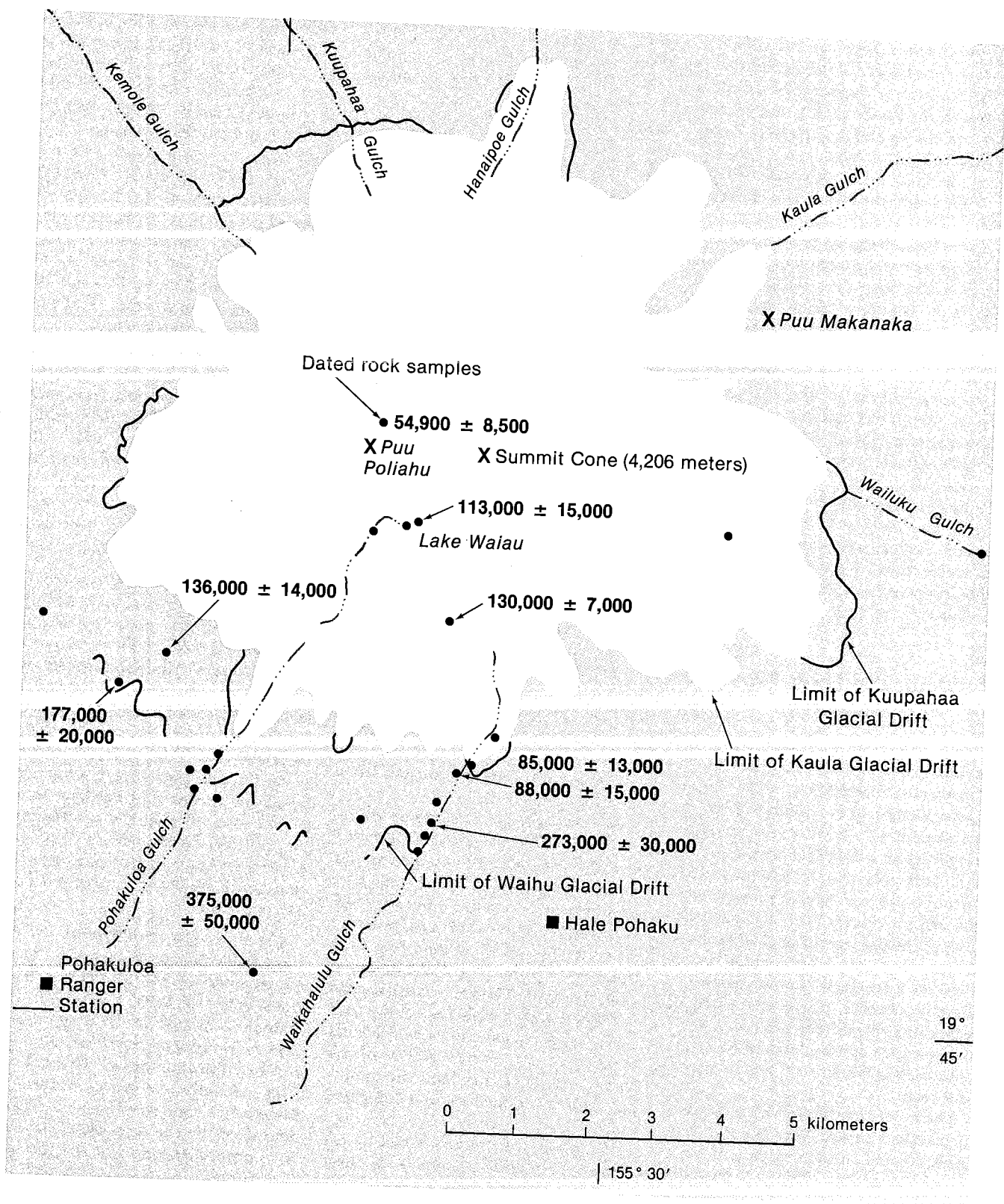
Dating of the volcanic rocks by radioisotope methods allows a close bracketing of the ages of glacial epi-

sodes and provides one of the best dated sequences of Late Pleistocene multiple glaciation known. The culminations of the four glacial events have been dated at approximately 20,000, 55,000, 135,000, and 250,000 years ago. Glacial drift from the youngest icecap can be traced almost continuously around the 4,205-meter peak at the 3,500-meter level. Outwash fans from earlier glaciations extend to elevations below 2,500 meters, near the level of the saddle between Mauna Kea and the neighboring volcanic piles of Mauna Loa and Kilauea to the south.

An unusual feature of the volcanic-glacial buildup is the presence of glassy surfaces and pillow structures in basalt associated with the two middle glacial sequences, indicating volcanic eruptions beneath the glacial material. Some cinder cones, of which there are approximately 300 on the upper slopes, show evidence of having been built into lakes as much as 150 meters deep.

The last icecap had disappeared by about 9,000 years ago, shortly after the withdrawal of the major continental ice sheets elsewhere. The presence of those icecaps on Mauna Kea indicates a lowering of the ancient snow line by many hundreds of meters below present levels. Such episodes probably coincided with the maximum extents of continental glaciation. Calculations based on extent and thicknesses of glacial deposits give the equilibrium-line altitudes for the successive periods of refrigeration and provide a record of climatic fluctuations during the past 250,000 years.

These climatic variations shown by the equilibrium profiles show a close correspondence with climatic fluctuations inferred from studies on the isotopic composition of foraminifera (tiny marine organisms) from deep-sea cores of the equatorial Pacific region. The volcanic and glacial record of Mauna Kea thus provides an independent check on the accuracy of the marine isotope chronology for the late Pleistocene.





Hawaiian glaciers. Geologic mapping around the summit of Mauna Kea volcano has defined the extent of separate ice caps that formed there during the most recent Ice Ages (left). The dating of associated volcanic rocks of comparable ages, such as the cinder cone and lava flows in contact with the boulders of a glacial moraine in the photo above, has permitted precise dating of the glacial sequences.

Ocean Sciences

The Foundation's ocean sciences programs develop fundamental knowledge about the oceans and the ocean basins by supporting a broad spectrum of basic research dealing with physical, chemical, geological, and biological processes. These processes control the composition and motions of ocean waters, the nature and distribution of marine life and chemical species, and the character of the solid earth beneath the sea. For many of these processes there is still much to be learned by studying them in relative isolation from the rest of the ocean. However, the ocean is, in fact, a complex dynamic system of water, living organisms, dissolved chemicals, and sedimentary particles that interact within the oceanic system. In addition, they and the ocean as a whole interact in important

ways with the atmosphere, with the sea floor, and with the bounding shoreline.

As our understanding of the oceans has broadened, so has the need for research with increased scope. Because of this, a growing portion of NSF's research is multidisciplinary, looking at several closely interrelated processes and/or components from the perspective of the oceanic system as a whole.

Concurrent with this evolution of ocean sciences has been an increase in marine-related activities and growing public recognition of the relevance of the oceanic environment. Such activities as fisheries, climate prediction, deep-sea mining, marine environmental pollution, exploration for oil and gas on the continental shelves, and naval

operations are all influenced by the marine environment and all have an impact on it. From a practical standpoint, NSF's basic research programs provide the basic understanding of oceanic processes necessary for the long-term management of these influences and impacts.

The Foundation supports basic oceanography through two research programs and a program for ship operations. Oceanography project support makes over 300 grants each year to permit individual scientists to study basic problems in physical oceanography, marine chemistry, submarine geology and geophysics, and biological oceanography. The International Decade of Ocean Exploration (IDOE) supports large-scale, long-term multidisciplinary projects, often with foreign participation. Four IDOE programs—environmental forecasting, environmental quality, seabed assessment, and living resources—fund research on the ocean's role in climate, food production, energy, minerals, and pollution management. Ships and other facilities and equipment to carry out these research projects are supported by the oceanographic facilities and support program, which provides two-thirds of the total support for the 29 research ships of the academic fleet. This program also upgrades these ships and facilities based on continuing review and evaluation of ship performance and material conditions and through the design and construction of replacement ships.

Nitrification and Denitrification in Marine Sediments

One of the major chemical cycles in the marine environment involves nitrogen, which exists in nature in a number of chemical forms. Some of these forms are major nutrients for the biosphere while others are better known as potential atmospheric pollu-

tants. As a result, the mechanisms and processes that control nitrogen compounds and their distributions in the marine environment represent a major problem area in marine chemistry.

One specific process important to maintaining the amounts and availability of nitrogen in the ocean is the diagenesis, or alteration, of nitrogen compounds in sediments. James Murray at the University of Washington is studying the chemistry of interstitial waters of marine sediments, with emphasis on the nitrogen cycle, as a direct attack on this problem of nutrient alteration and regeneration. Denitrification (any chemical reaction that results in the reduction of oxidized or fixed nitrogen compounds) in seawater having low oxygen content has been identified as a major sink for fixed nitrogen from the world oceans. Although a thorough investigation of denitrification in marine sediments in general has not been made, the role of denitrification in the sediments beneath the low oxygen waters in the eastern tropical North Pacific Ocean has been estimated to be minimal. If this minimal estimate is assumed to be the usual case, nitrogen-containing compounds that manage to reach the surface sediments through detrital settling would be degraded according to the classical picture, where bacterial oxidation of that sedimentary organic matter quickly uses up dissolved oxygen.

At that point, when the concentration of oxygen falls to near zero values, nitrate is then used for the oxidation of organic matter. And, when interstitial nitrate has been completely utilized, sulfate reduction then becomes the dominant microbiological process. Under normal steady state diagenetic conditions these processes would produce smoothly changing profiles of nitrate, nitrite, and ammonia concentrations versus depth in the sediments, showing no intermediate maxima or minima.

Murray and his coworkers, however, have recently obtained data from

sediments at a station in Puget Sound, Wash., that are inconsistent with that classical model. While the concentrations of interstitial nitrate, nitrite, and ammonia there did generally decrease with increasing depth, unexpected maxima were present at intermediate depths. The ammonia concentrations also generally increased with depth, but, again, a minimum in concentration was observed at intermediate depths closely corresponding to those for the nitrate and nitrite maxima. Because there is little or no sulfate reduction at depths of 25 to 30 centimeters, denitrification must be the dominant microbial process in this region. Consequently, there must be a nitrate source operating in these sediments to balance diffusional losses. That source would have to be biochemical in nature, since nitrate is not present in any marine mineral phases.

The results of this research, while preliminary, could have far-reaching implications. There is clear evidence of vertical zonation of the nitrification/denitrification process, with a strong suggestion that the mixing of interstitial and oxygenated bottom water could result from irrigation by burrowing benthic organisms. It also appears that a horizontally continuous layer could be formed where the population density of organisms is high enough so that the fields of influence of the individual organisms overlap. This irrigation mechanism could represent a significant means of chemical communication between bottom water and accumulating sediments. If such a process is indeed active and widespread, it presents the possibility that marine sediments may be a more important nitrogen sink than has previously been thought and, consequently, play a significant role in the nitrogen cycle in the oceans. Just as importantly, it points out the very substantial effects that biological processes may have on chemical reactions in sediments and on chemical transfers across the sediment-seawater interface.

Interspecies Competition in Marine Communities

Study of marine organisms and the communities they form has led to development of many fundamental concepts in biology. During the past decade studies by Robert Paine at the University of Washington and others demonstrated that intense interspecies competition for space was the most significant factor in structuring the intertidal community of attached organisms that cover rocks and other hard surfaces along the margins of temperate oceans. In these intertidal areas species diversity is relatively low. In addition, the competition is hierarchical and its outcome is very predictable. Each species holds a fixed position in an overall ranking of competitive ability, and a species of higher rank will always displace species of lower rank unless restrained by an outside influence such as a predator or storm damage. This relatively simple competitive system of the temperate rocky intertidal was widely accepted as a model for all benthic marine communities.

More recently, however, research by Jeremy Jackson and Leo Buss of Johns Hopkins University has demonstrated that this single model of competitive relationships in marine communities is far too simple and is inadequate to deal with a diverse subtidal community such as a tropical coral reef. Jackson and Buss examined competitive relationships among the roughly 300 species of cheilostome ectoproct bryozoans that occupy about half the cryptic, or hidden, surface area of Jamaican coral reefs. These bryozoans are the common lacelike colonies found encrusting hard surfaces like rock, driftwood, and shells throughout the world oceans.

Competition between these cryptic coral reef bryozoans usually occurs as encounters along the perimeters of colonies. Through careful attention to colony morphology and orientation, Jackson and Buss classified the encounters as a frontal, flank, or rear attack

and found that the encounters could result in one of three outcomes: (1) one colony can win and overgrow the other, (2) both colonies cease to grow and coexist along the boundary, or (3) the colonies fuse into a single colony.

No simple, hierarchical pattern of competitive advantage among the bryozoan species emerged from these studies. Instead, the competitive relationships formed a network pattern in which, for example, species A may usually outcompete species B, and species B may usually outcompete species C, but species C may often outcompete species A. Furthermore, numerous aspects of colony morphology and growth affected the outcome of competitions. The direction of attack and the condition of the antagonists were found statistically correlated with the pattern of outcomes. Thus, the outcomes of most competitions were uncertain, and changes in the community composition were unpredictable. This complex competition network found among the cryptic coral reef bryozoans appears to exist among many other groups of sessile (permanently attached) colonial organisms. Consequently, network competition may be the norm for the ocean, and the simple hierarchical competition of temperate rocky intertidal may be the exception.

Our exploitation of the environment for food and shelter has frequently had serious consequences, simply because we have not understood the role of competition in nature. Manipulation of the ecosystem has often resulted in a gross elimination of competition, with attendant secondary problems. It is through this kind of innovative study of small segments of the ecosystem, even apparently esoteric segments, that a concise picture of the workings of an unexpectedly complex system will be formed.

Carbonate Reefs

Fossil reef complexes and carbonate platforms contain more than a third of the world's reserves of petroleum, a

major share of the metallic ores, and an unusually sensitive and legible record of Earth history. Modern-day carbonate margins have long been looked at in order to gather clues to the locations and contents of ancient margins buried in geologic sections. Moreover, modern margins are valuable in their own right as the sites of industry, tourism, and aquaculture, as well as being centers of shipping. Residential pressures on margins like Florida, the Virgin Islands, and the Bahamas have made storm effects, beach stabilization, coastal erosion, and ground water reserves items of intense environmental concern.

Modern carbonate margins occur around the world at low latitudes; their ancient counterparts are found worldwide and span the entire geological depositional record. While studies of fossil reef complexes are valuable, they can only reveal the geologic structure

that remains after the reef has been altered by various geologic processes. If successful models of the carbonate margins are to be developed, then knowledge of modern processes is essential.

The shallow margins consist of reefs, shoals of carbonate sands, bare rock outcrops, buried rock ridges, fossil or nonactive sand bodies, and combinations of these elements. Sea level fluctuations over existing topography set up feedback loops where one kind of barrier generates a new type of barrier. Successive sea level events build complex stratigraphic histories, and deeper deposits are formed as reef and lagoon sediments are transported to the adjacent basins.

Until recently the processes by which the unconsolidated carbonated sediments become lithified or cemented together were largely unknown. Recent work by Robert Gins-



Ocean bottom reef. At a depth of 1,050 meters (3,450 feet) the research submersible *Alvin* photographed this 2-meter-high cliff of bedded chalk near the Great Bahama Bank. Such deep-sea limestone is formed over millions of years out of sediments being transported into the depths from the shallow, coastal areas. The processes by which limestone reefs grow are important to understanding the formation of oil deposits.

berg and Wolfgang Schlager of the University of Miami and Conrad Neumann of the University of North Carolina has developed a more detailed understanding of these processes. They are studying the reefs by direct observations and sample collection from research submersibles. Data from the submersible dives are combined with seismic profiling results, drill samples from the reefs, and sediment samples from the adjacent ocean basins. One significant result of these investigations is the discovery that two major types of lithification occur—seafloor and burial lithification.

Seafloor lithification produces crusts or layers of cemented rock that are rarely more than 10 feet thick. However, the process is very fast on a geologic time scale, less than 100,000 years, which enables the seaward-facing reef cliffs to maintain steep slopes and provide a foundation for further reef development. In contrast, burial diagenesis requires tens of millions of years to produce thick pervasive sequences of chalk and limestone. Thus the structure and shape of modern reefs and platforms are controlled by rapid lithification processes, but the ancient equivalent deposit may appear as a thick sequence of chinks and limestones.

These geologic models are now being tested by additional geochemical, structural, and field observations. Many details of the processes of deposition, lithification, and erosion of carbonate platforms are still imperfectly known. Although the cause of the rapid seafloor lithification of carbonate sediments is still unclear, it is quite clear that the process has a major effect on the development of potential reservoirs beneath carbonate banks. The significance of a two-stage development of carbonate margin structure and maintenance is only beginning to be appreciated now. This may require reexamination of concepts developed to explain the migration, entrapment, and alteration of organic material incorporated in reef structures.

International Decade of Ocean Exploration

As part of the International Decade of Ocean Exploration's environmental quality program a new project, SEAREX (Sea-Air Exchange), has been initiated to study sea-air exchange processes. Its specific objectives are: (1) to measure atmospheric fluxes of selected heavy metals, manmade organic compounds, and naturally occurring organic compounds; (2) to identify the sources for these substances in the marine atmosphere; and (3) to investigate mechanisms of exchange of these substances across the sea/air interface.

The first field studies in the SEAREX project will take place in the western Pacific on Eniwetok atoll, whose remoteness makes it ideal to evaluate the global extent of anthropogenic pollutants. An instrumented tower will be erected there to sample atmospheric fallout under both wet and dry conditions. In addition to measuring the rates of material falling or washing out of the atmosphere, SEAREX investigators will examine the chemical composition of wind-generated sea sprays, a mechanism by which metals and organic materials are transferred from the sea surface to the atmosphere.

Field work for the final phase of the Geochemical Ocean Section Study (GEOSECS) was completed in the past year with water sampling at 52 stations in the Indian Ocean. These samples will be analyzed for nutrients, metals, and particulate material. Preliminary calculations of the carbon dioxide pressure in surface water show that the Indian Ocean, like most of the Pacific and Atlantic, is a source of atmospheric CO₂.

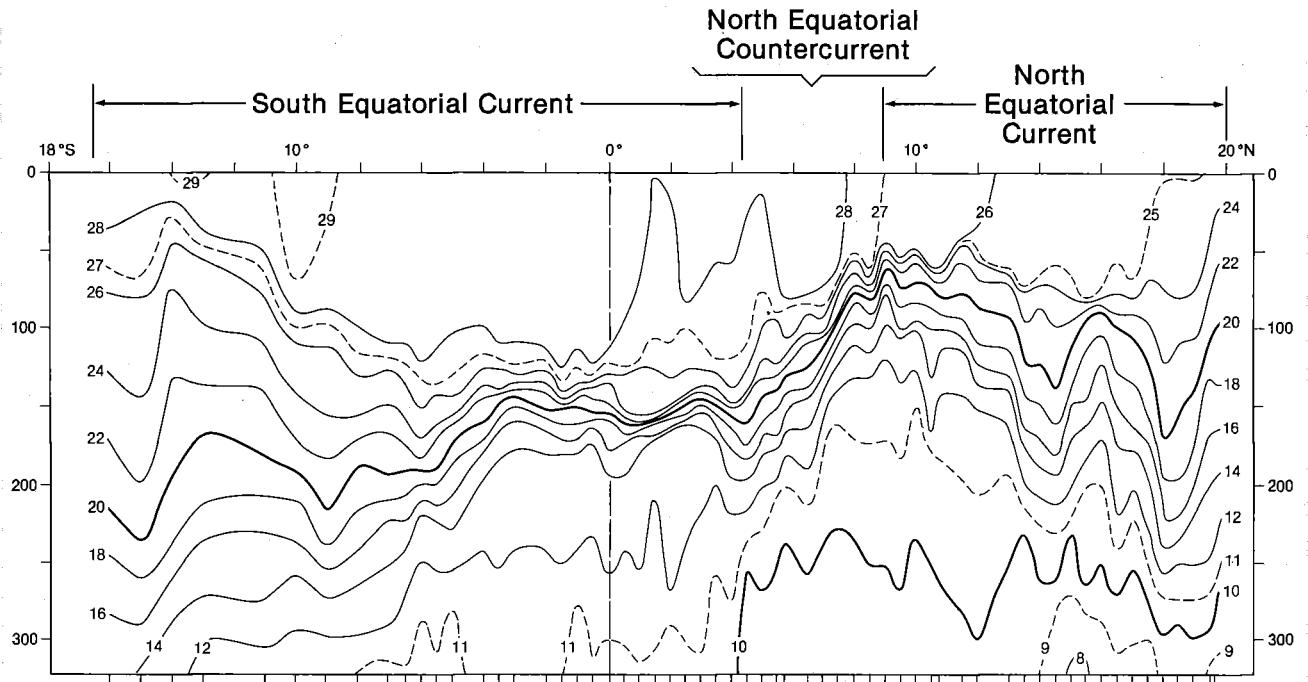
Supported by the seabed assessment program, scientists from a number of U.S. institutions are collaborating with French scientists in a study of the East Pacific Rise near the mouth of the Gulf of California. Project RISE (Rivera Submersible Experiment) will use both French and U.S. research submersibles for detailed investigations of the struc-

ture, tectonics, and vulcanism along the East Pacific Rise. Although a number of submersible studies of ridge crests have been undertaken in recent years, project RISE will be the first study of a ridge crest with a medium spreading rate. In this respect it will provide a valuable contrast to studies of slow-spreading ridges such as the Mid-Atlantic Ridge, studied during the earlier FAMOUS (French-American Mid-Ocean Undersea Studies) project.

Prior research along this section of the East Pacific Rise had identified an area near 21° N. latitude as a prime candidate for the RISE project. In January and February of 1978 the French submersible *Cyana* made 21 dives in the area. Three U.S. scientists participated in the French diving program. Perhaps the most striking difference between the RISE and FAMOUS areas is in the character of the basalt erupted onto the sea floor. In the FAMOUS area the basalt formed entirely as pillows, while in the RISE area the divers were surprised to find extensive "lava lake" deposits of rather smooth, featureless basalt.

Although a major goal of the French program was to locate hydrothermal vents such as those found on the Galapagos Rift in 1977, no active vents were located on this segment of the East Pacific Rise. On one of the last *Cyana* dives, however, a large field of dead clams was discovered. Since the Galapagos study showed that such extensive ridge crest faunal communities surround hydrothermal vents, hydrothermal circulation in this area probably ceased within the past few years.

In March and April of 1979 the U.S. research submersible *Alvin* will return to the 21° N. area to concentrate on geophysical investigations of the ridge crest. Using *Alvin's* impact hammer as an energy source, ocean bottom seismometers will be used to study structure of the top few hundred meters of the oceanic crust. Magnetic and gravity measurements will also be made from the submersible.



Ocean currents. As part of the North Pacific Experiment, changes in equatorial currents—which are linked to global weather patterns—are being studied intensively. This record shows results of remote temperature sensing along a north-south flight path between Hawaii and Tahiti (each contour represents a constant temperature). Boundaries of the major tropical currents are shown at the top.

In the environmental forecasting program's NORPAX (North Pacific Experiment) project, oceanographers have completed a preliminary but intensive study of currents in the central equatorial Pacific. Between November 1977 and February 1978 observations were made by aircraft on 13 round trips between Honolulu and Tahiti, on two cruises of the Hawaiian research vessel *Kana Keoki*, and by drifting buoys and current meters. Additional measurements were provided by instruments on nearby islands. The objective of the study was to determine a systematic sampling scheme for oceanographic measurements in the same area during 1979. The 1979 measurements will be closely coordinated with the First GARP Global Experiment, an intensive worldwide study of tropical winds.

Initial results of the study indicate that the large-scale current systems in the central equatorial Pacific change only slowly with time. To the north and south of the Equator, however, changes occur over short distances in both current and temperature records. During 1979 monthly cruises and aircraft flights will be used to observe low frequency fluctuations of the currents, to observe current response to changes in the winds, and to determine the seasonal cycles of the currents.

In the living resources program, analysis is continuing of data from the last field work in the Coastal Upwelling Ecosystem Study (CUEA). One important discovery, concerning the onshore-offshore distribution of biological organisms, shows that plants and animals are not uniformly distributed in a coastal upwelling ecosystem.

From CUEA studies off northwest Africa and Peru, small herbivorous copepods are recognized as inhabitants of the continental shelf regions, while larger zooplankton and fish occur at the shelf break. Apparently the convergence of currents related to upwelling at the shelf break tends to concentrate zooplankton and phytoplankton on which the fish feed.

Oceanographic Facilities and Support

Facilities and equipment for oceanography are a perennial concern to scientists and to the various advisory and oversight bodies with responsibilities for the health of national ocean programs. The Foundation is the lead agency in sustaining those ocean facilities serving the academic portion of the

Nation's oceanographic effort. With the continuing decline in support from other major agencies, the Foundation has assumed approximately two-thirds of the operating support of the 29-ship research fleet; moreover, it is virtually the only source of support for upgrading, maintaining, refitting, equipping, and replacing elements of this fleet.

In fiscal year 1978 NSF made a major award to Woods Hole Oceanographic Institution for the first of an anticipated series of midlife refits of fleet ships. The award was specifically for the reengining of the 210-foot research vessel *Atlantis II*. The term "midlife refit" applies generally to a major and unusual overhaul and upgrading or replacement program for a ship's basic machinery and structural elements. Such a refit is likely to be required between the 12th and 18th year of a ship's expected service life of about 30 years. The precise nature and cost of refits is a function of size, complexity, and condition of each particular ship, but the justification is essentially the same for all—namely, the continued operation of an effective research platform at reasonable cost.

The reengining of the R/V *Atlantis II* is a unique refit in that it involves the replacement of steam engines with diesel engines of the type powering other academic fleet ships. The steam engines of *Atlantis II* were originally selected for their low noise and vibration characteristics in an era—prior to the energy crisis—in which their high fuel consumption was acceptable. In recent years, however, rising fuel costs along with the larger engine room crew required for maintenance of the steam engines have combined to make *Atlantis II* the most costly ship in the fleet. The cost of conversion to diesel power will be amortized in several years by reduced operating costs, and the 15-year-old *Atlantis II* is expected to serve oceanography effectively for an additional 15 years.

Continuing efforts of a different nature to maintain both the opera-

tional and scientific capabilities of all fleet ships are sustained by the oceanographic equipment program. In fiscal year 1978 a detailed examination of the impact of this shared-use equipment program, now in existence for 8 years, was undertaken by NSF staff and consultants from the oceanographic community. One overwhelming conclusion of the study is that the ship operating institutions are not only dependent upon this small program for improvements for basic ship operations (e.g., navigation, communications, auxiliary machinery) and permanent shipboard scientific installations (e.g., winches, cranes, cables, acoustic systems) but also, to an increasing extent, for data collecting instruments essential to the performance of specific research undertakings (e.g., seawater and seafloor sampling, data management, shore laboratory analysis). Twenty-three grants totaling \$1.3 million were awarded for items representing this entire range of oceanographic outfitting.

The collective nature of oceanographic cruises—most of which combine and integrate the individual research of several investigators—together with the high cost of field equipment, urge upon this science a sharing approach. But, by the same token, the requirement for accurate calibration and proper handling of

instruments in a hostile environment impose special management problems. Thus the equipment study also emphasized the need to link NSF's modest technician support program to the management and maintenance of shared-use instrumentation. Fiscal year 1978 technician support for the major oceanographic institutions was approximately \$1.2 million.

The Foundation continued, in fiscal year 1978, to support design studies for coastal and polar ships. Two coastal designs, approved conceptually in fiscal year 1977, are being developed to the stage of final specifications for use in future construction. The need for a continuing program of ship construction to replace old ships and to modify fleet composition to meet changing research requirements has been underscored by reports of such groups as the National Advisory Council for Oceans and Atmosphere and the University National Oceanographic Laboratory System (UNOLS). UNOLS oversees and assists the complex scheduling of the academic fleet, which continues to be used predominantly by NSF-funded research programs directly in oceanography and also in global atmospheric programs, earthquake studies, polar research, and a wide range of biomedical studies. Use of the fleet reflects the multiplicity of scientific activities relating to the world oceans.

United States Antarctic Research

United States research and support operations in Antarctica constitute a year-round program funded and managed by the Foundation. This effort is unusual among the Foundation's programs because, in addition to supporting research relevant to a number of global scientific problems, it is the principal expression of U.S. national policy and interest in a world region.

Virtually all the Foundation's antarctic funds are expended as awards for research projects and operational support in Antarctica, but Foundation staff and a number of grantees participate in international workshops and negotiations that influence the composition of the research program. In the area of science, these exchanges frequently take place in the nongovern-

mental Scientific Committee for Antarctic Research, a component of the International Council of Scientific Unions. In the political arena, exchanges occur under terms of the Antarctic Treaty, which reserves the Antarctic for peaceful purposes, guarantees free access to all parts of the continent, and encourages scientific research.

These international discussions (and national ones too) have come to be dominated in recent years by concern for the potential for exploitation of resources and the environmental impact of exploitation should it occur. The discussions became intensive in fiscal year 1978. In October, the ninth Antarctic Treaty consultative meeting, in London, produced two key recommendations. The first urged the 13 consultative nations to "refrain from all exploration and exploitation of antarctic mineral resources while making progress toward the timely adoption of an agreed regime." The second recommended interim guidelines and establishment of a definitive regime for conservation of antarctic marine living resources. Some progress toward the living resources regime was made through the year in meetings at Canberra, Buenos Aires, and Washington.

Both recommendations noted the need for additional scientific data for development of rational management policies, conservation measures, and environmental safeguards. The Foundation supports basic research that will provide such data. However, the research program, summarized in the following paragraphs, generally remains balanced among the disciplines of geology, geophysics, glaciology, oceanography, biology, medicine, meteorology, and upper atmosphere physics.

Since the beginning of the U.S. Antarctic Research Program 20 years ago, geological reconnaissance has identified the structure and the history of much of Marie Byrd Land, the Transantarctic Mountains, portions of the Antarctic Peninsula, the Scotia Arc, and other locations. Parties operated

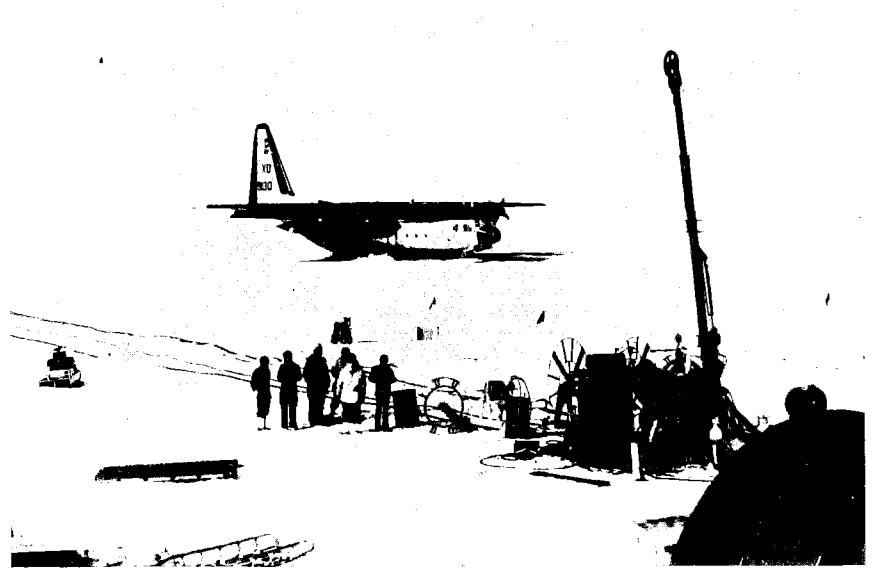
this season on the Hobbs and Ruppert Coasts of Marie Byrd Land, on the Orville Coast, along the northern Antarctic Peninsula, in southern Victoria Land, and in Enderby Land, East Antarctica. Meteorites were collected aseptically from the surface of the ice sheet and were taken for analysis to the Lunar Receiving Laboratory in Houston, Texas.

Glacial geology was concentrated in the McMurdo Sound area, where Ross Sea glaciations have occurred in the last several thousand years. How fluctuations in the size of these glaciations relate to world climate is yet to be determined.

A flame-jet drill penetrated the 420-meter-thick Ross Ice Shelf to enable sampling of the sea and sediments below. A 5-year project to measure movement of the ice shelf was completed. Airborne radio-echo sounding of the thickness of the ice sheet continued in both East and West Antarctica; 25,000 kilometers were flown. These projects and others aim at un-

derstanding the relationship of ice sheet activities to past and present global climate. An investigator aboard the research ship *Islas Orcadas* managed to retrieve from the sea a piece of an iceberg colored deep green; analysis revealed both organic and inorganic materials, but the cause of the green color is still unclear.

The Coast Guard icebreaker *Glacier* supported intensive physical oceanographic measurements in the southern Weddell Sea. Some 118 hydrographic stations were occupied in a grid with spacings of 10 kilometers. The work is aimed at understanding the mixing that leads to formation of bottom water near the edge of the continental shelf. Helicopters from *Glacier* put a buoy on a large tabular iceberg for tracking by satellite. Oceanographic measurements made at the Ross Ice Shelf drill site and from the icebreaker *Burton Island* in the Ross Sea gave information on circulation beneath the ice shelf and on interactions between glacial ice and the adjacent ocean. Ocean



Ross Ice Shelf. An LC-130 Hercules supply airplane arrives at Site J-9 in November 1977, where the flame-jet drill seen in the foreground later penetrated the 420-meter (1,378 feet) thick ice to retrieve water and sediment samples from below. The drill site is 587 kilometers (365 miles) from the main U.S. support station at McMurdo Sound.

waves measured at the drill site, several hundred kilometers south of the ice front, were found to have periods of 1 to 15 minutes and amplitudes of a few centimeters.

In April and May the research ship *Islas Orcadas* made a 54-day, 10,911-kilometer (6,781-mile) cruise in the southwest Atlantic sector of the southern ocean for sediment coring to elucidate the older geologic history of the region and to trace prior flow of antarctic deep water. A total of 120 stations yielded 69 complete piston cores. Gravimetric, magnetic, and seismic measurements were made to investigate the spreading regime and fracture zone trends of the tectonic plates in the area. Seventy-three conductivity/temperature versus depth casts were made to trace the present-day flow of antarctic deep water and the Polar Front (Antarctic Convergence).

Biological projects focused on the marine ecosystem. Micro-organisms collected from seawater beneath the Ross Ice Shelf drill site yielded a count of 8.7 to 12 million cells per liter. The data indicate a metabolically active planktonic biota, but do not establish an operational food web in this cold and dark place, since the populations could have flowed in from the Ross Sea. Zooplankton was studied in the Ross Sea and on the west coast of the Antarctic Peninsula; the life cycle of krill (*Euphausia superba*) received special attention using seawater aquaria at the U.S. station on Anvers Island. A long-term study of benthic communities in McMurdo Sound was concluded, yielding details of reproductive biology and survival for different age groups. Population, behavioral, and physiological studies continued on penguins, flying birds, and several species of seals. Terrestrial biology included a survey of insect populations, further investigation of the remarkable populations of micro-organisms living just beneath the surface of rocks, and an ecological study of lakes and soils in the ice-free valleys of southern Victoria Land.

Synoptic surface and upper air observations at the four U.S. year-round stations continued to contribute to the sparse Southern Hemisphere net of meteorological observing stations. Measurements continued at the geographic South Pole on a number of atmospheric constituents, including trace gases, aerosols, tritium, carbon dioxide, surface and total ozone, halocarbons, and N_2O . Measurements at this remote spot yielded global background levels and provide a basis for predicting climatic change.

Investigators continued to take advantage of Antarctica's high geomagnetic latitude for study of the magnetosphere and the ionosphere. The main facility for these studies is Siple Sta-

tion, which has a 100-kilowatt very low frequency transmitter and a receiver with a 21.4-kilometer-long dipole antenna that is geomagnetically conjugate to a receiver at Roberval, Quebec. The studies center on the interaction of waves and particles in the magnetosphere. Waves induced by the ground transmitter or by lightning propagate into space along magnetic field lines, grow in amplitude, and then interact strongly with particles, scattering some downward into the ionosphere, where they collide with ions or neutral particles, creating fresh ionization, X-rays, and optical emissions. Such effects are of fundamental interest both in radio communications and in solar/terrestrial physics.

Arctic Research

The arctic research program supports projects related to the environment and to the potential for resources. It comprises about half the arctic research supported by the Foundation; the other half is supported by various disciplinary programs.

Vast amounts of protein are harvested each year from the Bering Sea, whose fisheries comprise about 4 percent of the total world catch; nearly 75 percent of this quantity consists of Alaska (walleye) pollack (*Theragra chalcogramma*). The Bering Sea also supports extensive populations of marine mammals, birds, and other fishes. Despite this high productivity, the primary production does not appear excessive; it is typical for a subarctic ocean. The unexpectedly high secondary production is presumed to be a result of effective transfer between primary and higher trophic levels.

Processes and Resources of the Bering Sea (PROBES), now in its second year, is a project designed to understand these extraordinary transfer mechanisms. The hypothesis is that

oceanic features and the broad, shallow continental shelf favor this high production and exchange of biomass. PROBES uses the development of the life stages of the pollack as a biological indicator of ecosystem processes and mechanisms.

In April through early July 1978, observations by two research ships—the *Thompson* and the *Acona*—documented that the study area is influenced by two different water masses originating over the shelf and the open southern Bering Sea. The basic processes of organic matter transfer and synthesis in each are associated with different plant and animal communities and are phased separately. Just why these regimes stimulate high biotic productivity remains to be learned in a later phase of the project.

Four U.S. geological projects aimed at understanding the geologic history of the arctic island group of Svalbard took place during the past year. Svalbard has high significance to the geological history of the Greenland-Scandinavia area. Field work in July

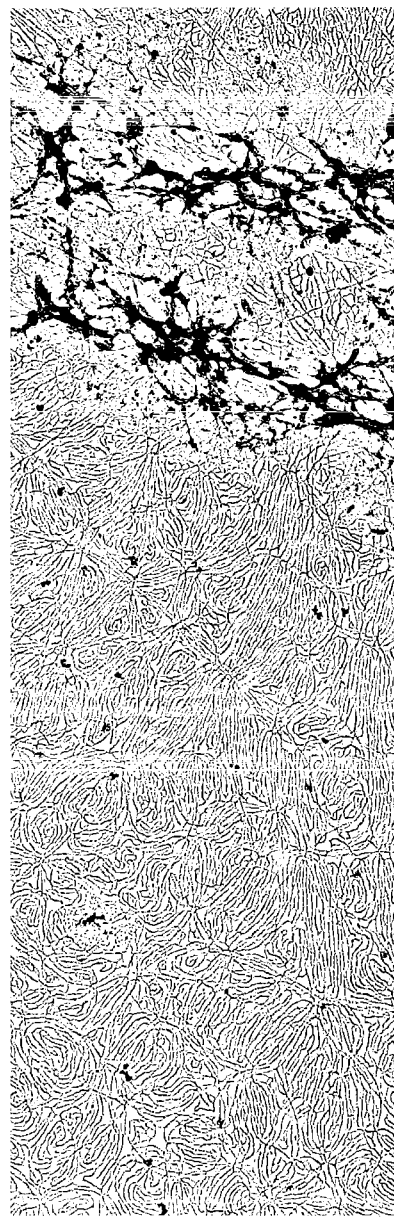
and August comprised mapping of Precambrian outcroppings over 150 square kilometers, study of Paleozoic stratigraphy, seismology, and geophysics, and glacial geology and morphology. Norway administers the islands under a 1920 treaty that grants mineral rights on an equal basis to the ten signatories, which include the United States.

U.S. geologists joined others from the United Kingdom, Denmark, and

the Greenland Geological Survey at Isua, Greenland, to do detailed surveying and sampling of the world's oldest known sedimentary rocks—3.8 billion years old. The objective was to understand the Precambrian environment of the area and to obtain evidence of organic molecules that are the precursors of life. Another party at Holsteinborg collected rock samples for age dating. Glaciologists studied calving of the rapidly moving Jacobshavn Gla-

cier, which drains a substantial portion of the Greenland ice sheet into Davis Strait.

In the Greenland Ice Sheet program, airborne radio-echo sounding of ice thickness and bedrock topography was performed in April by a Navy-operated antarctic airplane; in July and August ice core drilling and surface glaciology took place near Dye-3, a Distant Early Warning line station in southern Greenland.



Biological, Behavioral, and Social Sciences

3

Perhaps the most salient characteristic of research in biological, behavioral, and social sciences is its rich diversity. Subject matter ranges from molecular dynamics to complex ecosystems. Time perspectives range from the picoseconds of photochemical reactions to the millions of years involved in the cultural development of humankind. Techniques range from biochemical and biophysical procedures used, for example, to dissect membrane function to the qualitative case-study methods characteristic of work in the history and philosophy of science.

Despite this diversity, many technical and conceptual threads cut across apparently disparate areas of science to provide an ever-increasing number of interfaces from which emerge significant improvements in our ability both to pose and answer important questions. Basic research in biological, behavioral, and social sciences is certainly not unique in this regard, but these scientific areas are still relatively young. Interdisciplinary activity is accelerating rapidly, and its impact is visible in many areas. For example, evolution is now addressed in molecular terms with a tremendous increase in explanatory capability; plant scientists are now trying to specify the molecular processes underlying the regeneration of whole plants from vegetative cells; neuroscientists, concentrating on the nervous system/behavior link, are capitalizing upon in-

vertebrates with relatively simple nervous systems that are amenable to analysis in molecular terms. The molecular biology revolution of the past decades continues, but with an added dimension. Advances are not limited to the molecular level, but span many other facets and levels of biological and behavioral research and theory. The gains for society from this diffusion of knowledge, technique, and instrumentation are already substantial, but the long-term payoffs will be immense. Virtually every major problem faced by contemporary society—population, nutrition, energy—requires significant biological, behavioral, and social sciences knowledge and perspectives for solution. The Foundation's role in assuring a healthy base of fundamental

research that continually pushes back frontiers is pivotal to the ability of these scientific areas to contribute long-term solutions.

An indirect index of the excitement and opportunity that pervade the biological, behavioral, and social sciences research community is the increasing number of unsolicited proposals for research submitted in the face of decreasing expectations of support. From 1976 to 1978 the number of actions (awards, declinations, and withdrawals) taken by biological, behavioral, and social sciences programs increased approximately 48 percent (from 4,993 to about 7,400). Competitive success ratios have dropped from 40 percent to about 29 percent, despite a substantial increase in the programs' overall

Table 4
Biological, Behavioral, and Social Sciences
Fiscal Years 1976, Transition Quarter
(July 1–Sept. 30, 1976), 1977, and 1978

(Dollars in Millions)

	Fiscal Year 1976		Transition Quarter		Fiscal Year 1977		Fiscal Year 1978	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Physiology, Cellular, and Molecular Biology	1,053	\$ 43.69	279	\$12.00	1,169	\$ 51.34	1,275	\$ 57.64
Behavioral and Neural Sciences	539	19.69	140	5.47	619	23.81	737	28.47
Environmental Biology	534	26.84	156	7.15	587	30.17	607	31.49
Social Sciences	364	18.81	100	5.11	375	21.29	419	24.25
Total	2,490	\$109.03	675	\$29.73	2,750	\$126.61	3,038	\$141.85

SOURCE: Fiscal Years 1978, 1979, and 1980 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

budget. Even though the rapid pace of development in these areas of science has exceeded NSF's ability to support all of the meritorious projects or to support fully the most important research, the health, vitality, and prom-

ise of biological, behavioral, and social science research have never been greater. The Foundation is proud of its grantees' progress, a small portion of which is discussed on the following pages.

Physiology, Cellular, and Molecular Biology

During the past several decades, experimental biology has changed markedly. Several developments—for example, the sophisticated application of isotope tracer techniques along with improved methods of studying events at the molecular level—were instrumental in producing what is commonly called the “new biology.” The development of the double-helix model of the chromosome and the exploitation of the implications of this model produced new insights into molecular events at the genetic level, mechanisms of gene expression, and how genes regulate cellular activity. Much of the current research in physiology, cellular, and molecular biology grew out of these past discoveries.

Rapid advances also have been made in such supramolecular areas as organism development; regulation of and communication between cells, tissues, and organs; structure at cellular and subcellular levels; and functional integration of whole organisms. A few examples of these advances are the increased understanding of hormonal action in both plants and animals, the roles of cyclic adenylyl monophosphate and cyclic guanylyl monophosphate in mediating endocrine action, the discovery that these two substances are involved in regulating cell division and organ size, the discovery of the regulatory action of cell type by polar plasma in *Drosophila* eggs, and the analysis of sensors underlying the chemotactile response.

Such progress in basic biological research at all levels inevitably leads to

important applications. For instance, the identification and isolation of pheromones—chemical secretions that affect the behavior of other organisms of the same species—is leading to new approaches to insect control. Research on the metabolic pathways of bacterial life forms that produce methane may help to meet energy needs, as might research on bacterial forms that produce hydrogen. Advances in basic plant science are leading to improved productivity and will help meet world food needs.

A common link across many of these areas of biology is molecular biology, which has now become a tool in the investigation of structure and function at higher levels of organization. For example, the establishment of changes in membrane fluidity underlying temperature adaptation in some bacterial species, the elaboration of how the genetic machinery is involved in endocrine effects induced by steroid hormones, and the investigations of appearance of certain enzymes in explaining neonatal development of regulation all illustrate the applicability of molecular biology to other biological fields. The diffusion of molecular biology does not mean that the “new biology” is coming to an end. To the contrary, we now appreciate that there are many more unsolved problems at the molecular level that require extensive future work. Experimental biology has developed a new dimension wherein molecular techniques are used to investigate the mechanistic basis of a variety of supramolecular activities.

Structures of Biomolecules

In the past decade many areas of science have benefited tremendously by the development of X-ray crystallography and nuclear magnetic resonance (NMR) spectrometry techniques for defining molecular structure. Unfortunately, their application to biomolecules has been limited. In the case of X-rays, diffraction from planes of atoms within a crystal gives rise to reflections whose intensities contain the structural information. At a minimum, the number of reflections that must be measured to determine a structure for a specific spatial resolution is proportional to the molecular weight squared. Consequently, many of the proteins whose structures have been determined to date have molecular weights less than 25,000. Similarly, the difficulty with NMR is that the number of signals from magnetic nuclei increases with the size and complexity of the molecule. As a result, the spectra of biomolecules obtained with existing NMR spectrometers contain broad bands composed of overlapping peaks. However, recent developments are now extending the applicability of both techniques to biological structures.

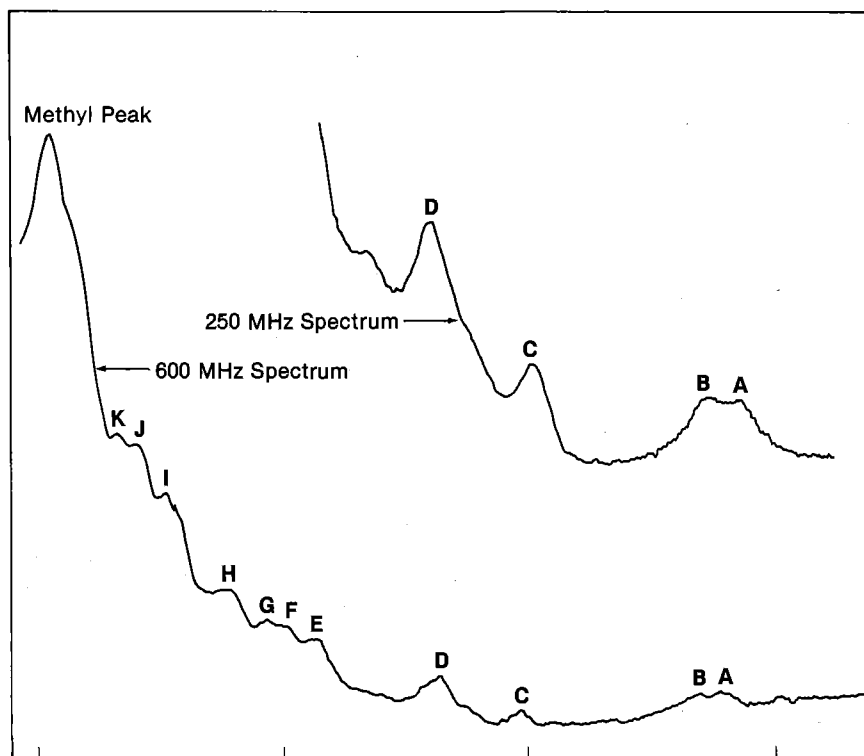
Conventional X-ray diffractometers measure a single reflection at a time. Now Xuong Nguyen-huu has built an X-ray detector at the University of California, San Diego (UCSD), that can collect intensity data an order of magnitude faster than by conventional means. Fine wires are arranged in a grid with spacings of 1 millimeter to give a compact square array with 64,000 intersections; each place where two wires cross is an individual detector. Electronic delay lines then pinpoint which detector is struck by an incident X-ray. Using Xuong's multi-wire area detector, Joseph Kraut and his students at UCSD made 80,000 intensity measurements of 12,000 reflections from a crystal of the enzyme dehydrofolate reductase during its 6-day lifetime in the X-ray beam. Only

three crystals, one each of the native protein and two heavy atom derivatives, were needed to obtain an atomic resolution map of the enzyme's structure. All the data were collected in just a few weeks. Without the new detector, many months and dozens of crystals would have been needed, or the investigators would have had to content themselves with a bare outline of the protein's backbone chain.

Building on Xuong's work, Martin Deusch and his colleagues at the Massachusetts Institute of Technology are building a second-generation area detector that will improve the resolution and further increase the size of macromolecular structures that can be determined by X-ray diffraction. In studies of enzyme-catalyzed reactions, it may even be possible to determine the three-dimensional structures of some intermediates that are metastable at subzero temperatures.

Resolving the broad composite bands in the NMR spectra of complex biomolecules observed with existing spectrometers will require higher magnetic fields than are now used. To achieve this, Joseph Dadok and Aksel Bothner-by of Carnegie-Mellon University have built a 600-MHz (megahertz) nuclear magnetic resonance instrument. The key to their success is the development, undertaken in cooperation with Intermagnetics General Corporation, of a superconducting solenoid capable of maintaining a field of 141 kilogauss with the stability and homogeneity required for NMR measurements.

In December 1977, proton spectra were obtained at full field strength and 600 MHz with a resolution of one part in a billion. Spectra were obtained on the high field side of the methyl resonance of carbonmonoxyhemoglobin at 250 and at 600 MHz. Seven additional peaks were also obtained at the higher frequency. The 600-MHz spectrum was taken on the floor of the Intermagnetics General factory with the electronics from the Carnegie-Mellon 250-MHz instrument and a makeshift



Improved information. A technique—nuclear magnetic resonance—used for studying molecular structures has been markedly improved by the incorporation of a higher magnetic field. A preliminary test of the new instrument on a large biomolecule—carbonmonoxyhemoglobin A—further resolves the fine details of signals produced by magnetic nuclei, with the higher frequency spectrum now possible showing seven additional peaks on the high field side of the methyl signal.

probe. The wide bore magnet that was used is being incorporated into a Fourier transform spectrometer with multinuclear capability and is scheduled to begin operation as a separate facility in January 1979. This instrument should greatly increase the information about biomolecules obtainable from NMR measurements.

Interactions Between Proteins and Nucleic Acids

As more has been learned about the properties of purified large molecules, it has become possible to ask how these molecules interact with each other to produce functioning cell components. Understanding how the interactions

occur will obviously enhance our knowledge of molecular genetics, cell differentiation, and regulation of cellular activity.

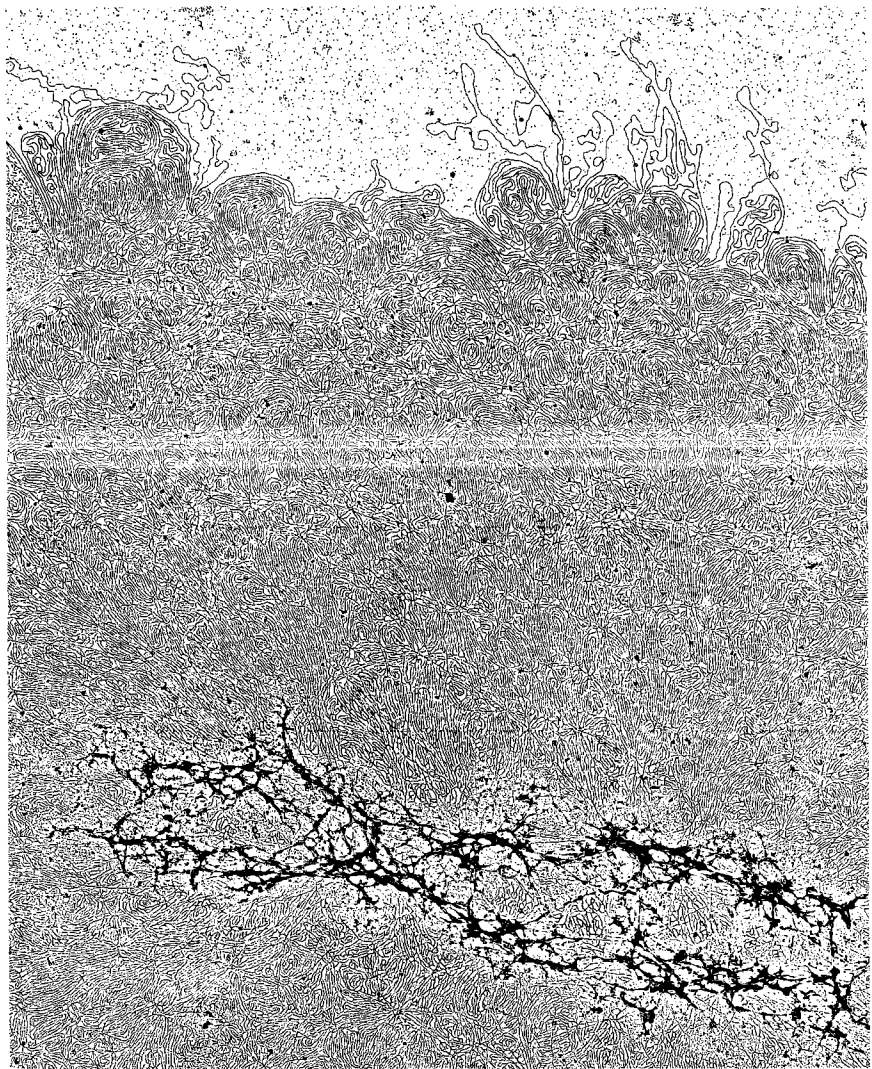
For example, the binding of proteins to nucleic acids is one area where current techniques are able to reveal much about how such interactions occur. The NSF *Annual Report* for 1975 described how it was found that the DNA in chromosomes is combined with simple proteins (histones) in a regular manner to give rise to a string of beads (nucleosomes). Since then, Ada Olins at the University of Tennessee has determined that each nucleosome contains two each of the four histones H2A, H2B, H3, and H4. Kensal Van Holde at Oregon State University has shown that a fifth histone, H1, is in-

volved in the length of DNA between nucleosomes. Moreover, Jack Griffith at the University of Tennessee has dehas found structures similar to nucleosomes in bacteria. This is surprising because histones have never been found in bacterial cells; thus some other protein probably serves the same function in bacteria as histones do in higher organisms.

The role of histones is being further elucidated by Ulrich Laemmli at Princeton University, who recently has shown that after the histones and the majority of nonhistone proteins have been removed from human chromosomes, the chromosomal DNA remains in an organized and reasonably compact structure. He also has shown that it is possible to use enzymes to digest away almost all of the DNA from chromosomes and still observe a protein "scaffold" with the shape of the original chromosome. This observation shows that basic chromosomal structure is maintained by protein rather than by DNA, which is the macromolecule that transmits genetic information.

A related area of research that has shown important progress in the past year concerns ribosomes—which exist in the thousands in every living cell. It is on these ribosomes that messenger RNA molecules, copied from chromosomal DNA, are translated into proteins. These complicated ribosome structures each consist of a large and small subunit and contain a total of 3 different RNA molecules and 53 different proteins. Masayasu Nomura and his colleagues at the University of Wisconsin were able to purify the individual proteins and reassemble functional subunits from the proteins and RNA molecules. This enabled a variety of physical techniques to be used to determine the three-dimensional structure of the ribosomes, and paved the way for assembly mapping.

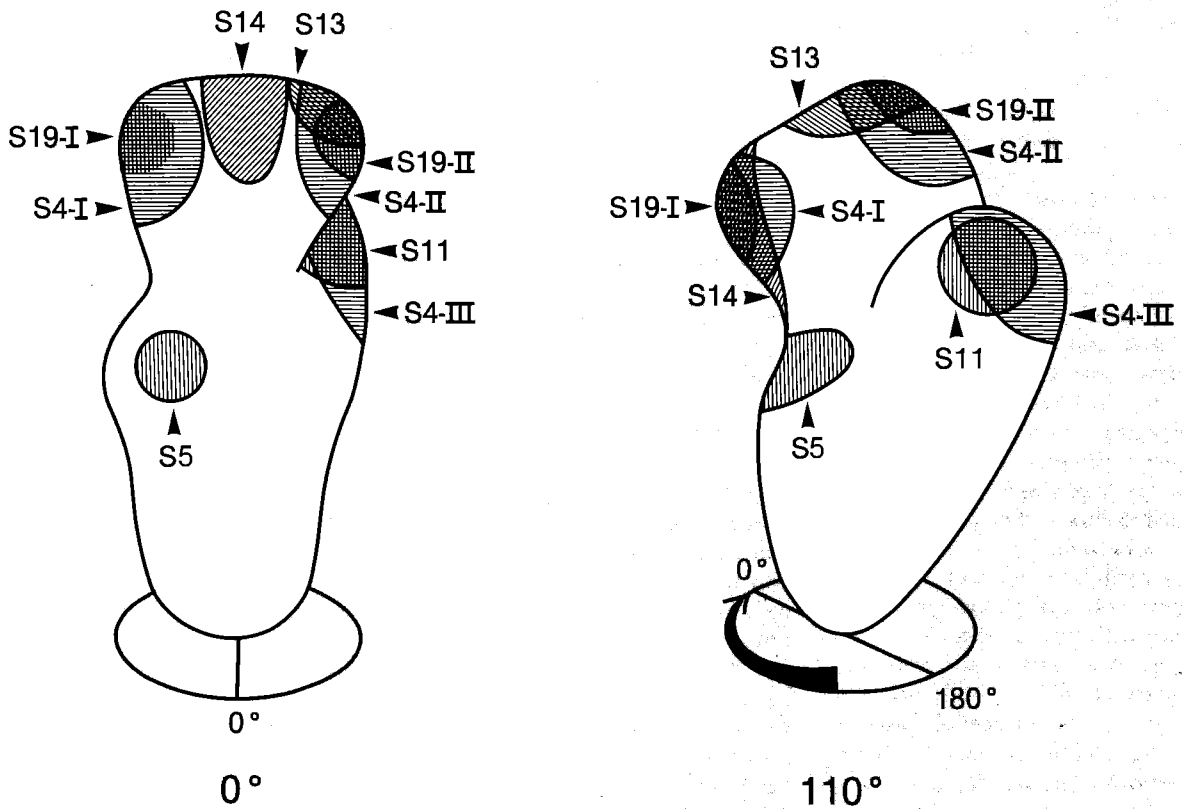
Charles Canter at Columbia University is measuring the distances between protein molecules by labeling purified proteins with fluorescent



Central structure. This electron micrograph of a human chromosome—taken after removal of most of the proteins normally present there—shows a central protein "scaffold" (in the lower part of the picture) surrounded by a halo of DNA. The scaffold, and the DNA, determine the chromosome's structure.

reagents. If two proteins are labeled and the rest are unlabeled, distances between the proteins in reconstituted ribosomes can be determined by measuring energy transfer between the fluorescent dyes. By replacing hydrogen with deuterium in selected proteins, Donald Engleman and Peter Moore at Yale University, working with Benno Schoenborn at the Brookhaven National Laboratory, use neu-

tron scattering to measure the distances between pairs of proteins. Finally, James Lake at the University of California, Los Angeles, collaborating with Nomura and with Lawrence Kahan at the University of Wisconsin, is using a technique called immunoelectromicroscopy. With this technique, antibodies specific to individual proteins can be added to complete subunits, and the points at which the



Structure of ribosomes. Ribosomes, the sites within cells where proteins are manufactured, are themselves made up of 53 different proteins. How these proteins fit together controls the function of the ribosome. A new technique adds antibodies to specific proteins to a subunit of the ribosome; where each kind of antibody binds to its specific protein (shown as darker areas) can be seen in the electron microscope, thus giving information about the three-dimensional structure of the ribosome.

antibody molecules bind can be seen in the electron microscope. There is a consistency in the results that these different techniques have provided, and a three-dimensional structure of the ribosome is emerging.

Physiology of Membranes

A vital aspect of biological research today is the fusion of traditional disciplines—such as biochemistry, physiology, anatomy, cytology—into “molecular physiology.” Molecular physiology attempts to answer the question of how organelles, cells, or

tissues perform their diverse functions. One of the areas that aims at the resynthesis of the whole from its parts is the physiology and biochemistry of membranes, the outer layers of cells. The revolution in membrane theory initiated in the 1960’s by cell biochemist Peter Mitchel at the Glynn Research Laboratory in Cornwall, England, is transforming our perception of life processes as radically as molecular genetics did two decades ago. Although enormous advances in knowledge about membranes at the cellular level have been made, owing chiefly to chemiosmotic theory, unanswered questions remain concerning the mo-

lecular mechanisms of membrane operation.

Many biological processes depend on “signals” received and transmitted via the membrane. For example, hormones bind to a receptor on one surface of a membrane and activate an enzyme on the other; antigens bind to an antibody embedded in the lymphocyte membrane, and the cell responds by proliferating or by manufacturing more antibody; cells interact at their surfaces and initiate phagocytosis, fertilization, or their own joining into a tissue; and drugs, toxins, carcinogens, lectins, phytotoxins, and hormones act via a membrane. The molec-

ular basis for transmembrane action is receiving increased attention.

Many of the processes of life depend on the generation or modulation of ion fluxes (especially of calcium) in the cell. Therefore, electrophysiological analysis has been added to the technical repertoire of cell biologists. Recent developments about the currents of hydrogen, sodium, and other ions that flow across membranes show that these fluxes serve functions other than those included under "bioenergetics." L. F. Jaffee and coworkers at Purdue University have found that a current of calcium is involved in controlling developmental events and localizing embryonic growth and that growth patterns may be altered by manipulating calcium fluxes. The importance of these observations goes beyond just developmental and cellular biology. Ion transport not only supplies metabolic enzymes with inorganic cofactors but also generates power and is now seen to be part of the way cells organize themselves in the intracellular matrix.

The first step in the action of many peptide hormones, including insulin, is the binding of the hormone to specific receptors on the surface, or cell membrane, of the target cells. The basic concepts about receptors and hormones were formulated over 50 years ago, but our understanding of receptors has advanced only recently. Modern studies show that the receptor is actively regulated in a wide range of physiological and pathological states. The affinity of hormone for receptor and the concentration of receptor respond rapidly to events inside and outside the target cell. For example, most diabetic patients have been found to have abnormalities of their insulin receptors that correlate with abnormalities in glucose tolerances and insulin sensitivity. These findings suggest that receptor abnormalities play an important role in human disorders.

With the development of improved methods for isolating membranes, rapid progress is occurring at the molecular level. Fractionation and reconsti-

tution of membranes already provide evidence of the relationships between the transport of ions and biological control mechanisms, but the search for regulatory factors is expanding. Understanding the molecular basis of membrane physiology in animals and plants plays a critical role in numerous biological applications. The impacts from such research will be widespread, with significance for marine animals in the aquatic food chain, food sciences generally, human diseases and suffering, and the design and effective use of medicinal drugs.

Plant Cell Culture

In 1902, Gottlieb Haberlandt published a report of his study of the culture of single leaf cells. Haberlandt was able to maintain the isolated living cells for up to a month, though they did not divide. Haberlandt was discouraged but nevertheless ended his report by stating, "I believe I am not making too bold a prediction if I point to the possibility that in this way one could successfully produce cultured embryos from vegetative cells."

It is now well established that embryos, even entire plants, can be regenerated from vegetative cells. What remains unknown are the underlying mechanisms involved. Present research focuses on both the regeneration of entire plants from protoplasts (a single plant cell minus its cellulose wall) and on the differentiation process itself.

The plant cell culture technique provides unique opportunities to investigate the cellular and molecular basis of differentiation. The fact that whole plants can be regenerated from the progeny of single differentiated cells is evidence that developmental events do not require fundamental changes in the genetic material. Instead, an orderly progression of events produces a multicellular organism. The basis of this process, called epigenesis, is being investigated by Fred Meins at the University of Illinois using tobacco cell

cultures. In these cells a requirement for certain substances known as cell division factors (CDF) can be induced and then reversed by addition of CDF itself. Meins is testing the hypothesis that this trait, as well as other epigenetic events, involves a feedback loop mechanism; i.e., the addition and presence of a specific CDF ensures that more of the same substance will be produced. In such a way, epigenetic changes may be regulated.

The research of James Shepard at Kansas State University illustrates how such basic information can be applied to produce plants with desirable characteristics from single cells. Shepard was studying the structure and antigenic characteristics of potato virus X when he conceived the idea that he might obtain potato plants resistant to the virus by selecting single resistant cells and inducing them to regenerate entire plants. Because it was difficult to culture potato cells, he first used tobacco cells, for which culture methods had been defined. He and his coworkers isolated protoplasts from leaves infected with the virus and then induced the protoplasts to divide and produce populations of cells. Plants regenerated from these cultures were screened for resistance to the virus by comparing the number of lesions produced in regenerated plants with the number produced in wild plants. Results showed an increased resistance in the regenerated plants. Now Shepard is working with a food crop plant, the Russet Burbank potato, the popular baking potato. By manipulating the CDF requirements through successive transfers of protoplasts to altered media, thus putting to practical use basic information of epigenesis, he has been able to regenerate plants. Present work, supported as part of NSF's Applied Science and Research Applications programs, focuses on fusion of protoplasts of virus-resistant plants to Russet protoplasts, which are extremely susceptible to a number of diseases, and field testing plants regenerated from these fused cells.

Behavioral and Neural Sciences

Neuroscience and cognitive science are the most rapidly advancing research areas being supported by NSF programs in the behavioral and neural sciences. In neuroscience the use of simple systems, together with new staining techniques, has greatly expanded our ability to study, at the cellular level, the nervous system's role in the production of behavior. Cognitive science constitutes an emerging area of inter- and multidisciplinary research addressing the human ability to gain and use knowledge and to process information. New innovative methods allow increasingly objective and quantitative investigation of mental processes, including the use of language.

Other areas of behavioral science have been active as well and, indeed, the vitality and opportunity for continued growth remains high. Two NSF initiatives in anthropology are especially noteworthy. In the newly implemented program for support of systematic anthropological research collections, 34 proposals were received in fiscal year 1978 and 10 awards made. The initial investment of approximately \$300,000 will significantly enhance research utilizing these valuable collections. The second area, research on human origins, is reaching a sophisticated stage in which a well coordinated international program of research can be expected to yield substantial new understanding. (Public interest in such research is evident from the demand for the November 7, 1977, issue of *Time*, which reported on Richard Leakey's work in this area. This was the largest selling issue of *Time* in 1977.) A conference on human-origin research was organized and conducted at the Foundation in May 1978. The conference report was discussed at the International Congress of Anthropological and Ethnological Sciences

in New Delhi, India, in December 1978.

As methods and techniques for studying the development of complex behavior in humans and other animals have improved in the past few years, the number of high-quality proposals received and the amount of NSF support have increased. Research examining the role of early experience on social attachment, acquisition of language, problem-solving ability, and temperament illustrates how genetic heritage and environmental influences interact in determining human and animal behavior.

An exciting development in the laboratory study of animal learning and motivation is the integration of theoretical and empirical work on the nature of reward processes. This work combines ideas from the study of species-typical behavior, evolutionary biology, and microeconomics. Investigation of how behavior is controlled by the scheduling of rewards, such as food, and the context within which the schedule operates is leading to new understanding of basic timing, counting, and memory mechanisms in animals. It is also providing information on how these mechanisms may guide foraging strategies in the wild.

Recent theoretical and experimental studies of vision have laid the groundwork for advances in the understanding of visual perception. A new conceptual development makes use of the linear systems approach, which relies on Fourier analysis and synthesis as a mathematical tool. Any waveform, such as that representing the distribution of a pattern of light on the retina, can be synthesized from a number of sinusoidal components. For several years psychophysicists have been demonstrating that the visual system works "as if" it were processing such components. Recently, electrophysio-

logical work has provided convincing support for a linear systems viewpoint. This general approach may provide the necessary key to the successful use of computers in reading patterns and illustrates the vital importance of both perceptual and physiological approaches to questions of common interest.

Cognitive Representation

A basic controversy among cognitive scientists concerns the nature of our mental representation of the world. Some theorists maintain that the information stored in long-term memory is in the form of a single abstract code that represents not only factual knowledge but also physical and visual information, such as the kind of knowledge that permits recognition of faces or placement of hands to catch a ball.

Other researchers propose a dual-code theory of representation. According to this theory there are two distinct memory stores or codes, called visual and verbal memories. Verbal memory is contacted when language is comprehended; visual memory, when pictures are perceived. The nature of the representation in these two memory stores differs in somewhat the same way that a sentence differs from a picture: The verbal memory stores propositions and the visual memory stores images.

Lynn Cooper at Cornell University believes that imagery plays as fundamental a role in cognitive representation as do propositions. In work extending and refining earlier research by Roger Shepard at Stanford University (reported in the 1974 *NSF Annual Report*), she is investigating the phenomenon of "mental rotation." Cooper shows her subjects a picture of an unfamiliar shape and asks the subjects to imagine the shape rotating in space. While they are doing this, she shows them another picture, which is either the same shape or a slightly different shape, and asks the subjects to judge

whether the second picture is the same as or different from the first. Sometimes the second shape has been rotated to an altered angle with respect to the first.

The amount of time it takes subjects to make the same/different judgment is measured. When the second image is in the angle the subjects are "expecting" (that is, when it is at an angle corresponding to the angle their mental image of the shape had attained at that point in their mental rotation of it) they are able to make the judgment significantly more quickly than when it is at an unexpected angle. The time required for the same/different judgment is constant for any angle of the second shape, as long as it is expected. The greater the departure from the expected orientation, the longer the time period required for the subjects to make the judgment.

By systematically varying the shape displayed, Cooper has been able to show that this phenomenon is independent of the complexity or any other inherent property of the rotating shape. Her results thus provide further support for the hypothesis that our cognitive representation crucially involves representations of a visual type, which can undergo continuous transformations that simulate physical processes in the external world, such as rotation around an axis. The systematic transformations inferred from this and related work provide physiologists with an intriguing neural process to explore. Determining how and where such transformations occur in the human brain will not be easy, but even partial answers should provide important insight into how the human brain functions.

Invertebrate Neurobiology

The human brain has billions of cells and multiple times as many connections. While noninvasive techniques, using healthy subjects and subjects with brain dysfunction, provide some information about how the central



Nervous system. The enzyme horseradish peroxidase, if injected into a cell, can be detected subsequently in the progeny cells that result from division. In his study of nervous system development, Gunther Stent at Berkeley emplaced the enzyme in one of the two cells in the very young leech embryo that give rise to the adult nervous system. Later, following cell division, one half of the embryo's developing nervous system, labeled with the enzyme, can be clearly visualized. This technique permits tracing the neural development through many stages of growth.

nervous system functions, the most promising approaches to understanding the cellular basis of behavior are emerging from the study of simpler organisms. Invertebrates have been utilized successfully for several reasons: (1) their large, easily recognizable cells can be studied electrophysiologically and biochemically; (2) their nervous systems survive well in isolation; (3) their many neurons that do not vary and can be repeatedly located from animal to animal facilitate study of the developmental history of a sin-

gle neuron; and (4) their nervous system, consisting of only a few neurons, makes it relatively easy to study the neural basis of simple behaviors.

Gunther Stent at the University of California, Berkeley, is studying the embryonic development of the leech nervous system. Having analyzed neural circuits responsible for movement in adult leeches, he is attempting to elucidate the developmental mechanisms that give rise to these neural circuits. Using a new technique of intracellular tracer enzyme injection,

he is able to analyze nerve cell lineage. Leech eggs, which may be raised from the uncleaved state in a simple salt solution, undergo orderly cleavages to produce easily detected pairs of large cells, or teloblasts, which give rise to most of the tissues of the adult, including the nervous system. Cell cleavages leading to the teloblasts can be observed under the dissecting microscope. An enzyme, horseradish peroxidase, which leaves behind an identifiable reaction product, can be injected into identifiable cells at very early stages of development. With continuing development, the lineal descendants of the injected cells thus receive some of the injected enzyme along with the parental cytoplasm. Intracellular techniques that allow electrical recording from a single nerve cell followed by injection with horseradish peroxidase for visualization are also being utilized. This systematic approach is a very powerful way to gain insight into the development of nervous systems.

Graham Hoyle at the University of Oregon is using another organism with a simple nervous system, the locust, to study the cellular basis of learning. The locust learns readily through simple conditioning procedures. The animal can learn to exhibit a specified behavior not only to obtain a food reward but also to avoid or escape unpleasant ambient temperatures and an annoying vibratory stimulus. Using electro-physiological recording, Hoyle has identified the motor neurons controlling leg movement and is also investigating the sensory pathways.

James Schwartz at Columbia University, a neurochemist, is utilizing a single identified neuron in the central nervous system of the giant sea slug, *Aplysia*, to study axonal transport. By making use of an intracellular pressure injection system, he can introduce small volumes of concentrated radioactive precursors, proteins, or small particles directly into the cell body. Kinetic analysis allows for direct microscopic observation of the movement of the

labeled particles. Two transport systems have been identified for the flow of cytoplasm through the neuron, one fast (about 400 millimeters per day) and one slow (about 0.5 to 3 millimeters per day). *Aplysia* lends itself to a large number of biochemical and immunocytochemical manipulations on these systems.

These examples illustrate how invertebrate preparations are promoting

the convergence of developmental, anatomical, physiological, and biochemical approaches to provide information about the cellular basis of nervous system function and formation. As better understanding of the fundamental principles of neuron systems in these relatively simple organisms is gained, neuroscientists will be able to deal more effectively with the infinitely more complex human brain.

Environmental Biology

NSF supports basic research in the broad areas of systematic and population biology, ecology, and ecosystem studies. In addition, it provides limited support for a variety of biological research resources, such as systematic collections of national importance, sites for field research, and culture collections.

The specific interactions that regulate the distribution and abundance of the species of plants, animals, and micro-organisms that collectively constitute communities and ecosystems is an area of high interest in current ecological research. Two recent studies, described on the following pages, illustrate the progress resulting from this interest. One examines the partitioning of resources among littoral-zone fish in lakes and among plant species in old fields and prairie. The other examines the effects of vertebrate and invertebrate herbivores on the metabolism and productivity of the prairie plants on which they graze.

Evolutionary biologists continue to supplement traditional methods of assessing present and past relationships with analytic techniques probing molecular structure. Of these new biochemical methodologies, those providing direct quantitative comparison of DNA from different species promise to reveal average rates of change of the

basic genetic material. For example, birds constitute the most completely known large group of animals, and few species exist that have not been described. Nonetheless, our understanding of the origins and interrelationships of many of the subgroups of birds is problematic. The third project described in this section illustrates the use of direct DNA comparison to approach these problems.

Resource Partitioning

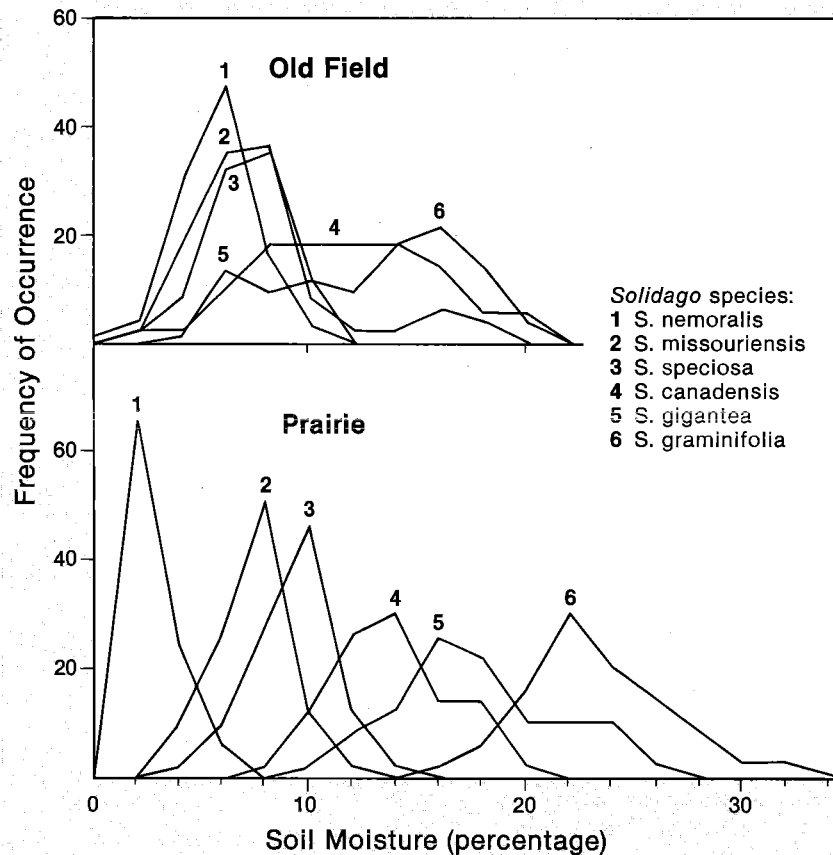
Competition among species for the use of environmental resources has long been one of the major foci of research in ecology. Over the years, field and laboratory observations have contributed to the growth of an extensive body of information and theory about how competition influences the distribution and abundance of species and how it determines the composition of plant and animal communities. Generally, these observations were based on only a few species and often reflected highly simplified environmental conditions. It was easy to show that some species exerted strong and direct detrimental influences on others and thereby influenced the use of resources. But the heart of the question—whether these differential efficiencies in exploitation of resources that were in short supply were an

important restrictive mechanism in nature—remained unanswered. Recent studies address this question. At Michigan State University's Kellogg Biological Station, Earl Werner, collaborating with Donald Hall and Patricia Werner, is studying resource partitioning among species of both freshwater fish and old field plants in order to determine the precise mechanisms of competition in natural communities.

Earl Werner and Hall are concentrating on communities of centrarchid fish, the family containing the bass and sunfish, that dominate the faunas of freshwater ponds and lakes in the Eastern United States. Methods range from censusing fish populations in natural situations (using SCUBA techniques) to studying feeding activities of individual fish under closely controlled conditions in the laboratory. Werner also experimentally manipulates species combinations in outdoor artificial ponds in which habitat conditions are controlled.

Werner and Hall analyzed partitioning among species by stocking three common species of the same genus of sunfish—bluegill, green sunfish, and pumpkinseed—in four combinations: together in equal numbers in one artificial pond, and each species separately in otherwise identical ponds. When stocked separately, the diets of the three species are quite similar; all feed on prey living in the preferred forage vegetation. But when the three species are stocked together, only the green sunfish occupies the preferred habitat—littoral vegetation. The bluegill then preys principally in the open waters, while the pumpkinseed feeds in and above the sediments at the center of the pond.

In natural situations Werner and Hall found that populations of littoral-zone fish segregate by the place and time of their feeding activities, thereby partitioning food resources. Spatial segregation is reflected by depth distribution, such as is exhibited by the green sunfish, which clearly restricts its feeding to shallow waters.



Interspecies competition. Six species of goldenrod, when growing in climax prairie stands (mature, stable ecosystems), are clearly segregated in growth habit according to soil moisture. Five of those same species, growing in a younger community (abandoned farmland) show far less segregation. Experiments with these plants are leading to improved knowledge of the effects of competition on plant growth.

Alternatively, bluegills and largemouth bass, which have nearly identical depth distributions in midsummer, partition their food resources by food size rather than location. (The mouth of the latter is obviously adapted to larger prey items.) Clearly, the resource partitioning observed under natural conditions can result from restrictions due to interspecific competition such as was observed in the artificial pond experiments. (For this research, Earl Werner received the Ecological Society of America's 1978 Mercer Award for excellence of published research in ecology.)

In related research, Patricia Werner is concentrating on competitive processes among herbaceous plants that occupy early stages of secondary succession in forested areas, such as southern Michigan, but exist as members of mature climax prairie communities farther west. These plants, which exhibit a diversity of life forms, phenologies, and life-cycle patterns, offer broad opportunities for examining specific mechanisms of plant competition. For example, Werner has demonstrated that the low growing rosette that develops during the first year of the biennial European

teasel shades out the surrounding area, thus suppressing the growth of surrounding competitors and creating an opening in which young teasel seedlings can germinate in the next season. In its second year the original plant produces only a tall, slender, flowering stalk.

She is also studying competitive processes among six species of goldenrods that differ in growth form, vegetative reproduction, and soil moisture relations. All six species occur in climax prairie stands in Iowa, and five of them are found in successional old fields (i.e., in abandoned agricultural or pasture land) in southern Michigan. In old fields, these species show some limited segregation in response to difference in soil moisture. In the climax prairie community, however, this segregation is sharp and striking. The extent to which competition is directly responsible for the partial segregation in field communities of perhaps 25 years in age and strong segregation in climax communities that have been undisturbed for centuries is being determined.

Shoots of each species, taken from vegetative clones, were transplanted at different points along the moisture gradients in both prairie and field. The growth of the shoots is being followed both in the face of competition from other plants and in the absence of such competition. Transplants of field plants to prairie sites, and vice versa, also have been done to determine the extent to which local populations are genetically adapted to their regional conditions. By combining field studies with laboratory investigations, valuable new insights of competitive processes in plants are being gained.

Impact of Herbivory on Plant Growth, Metabolism, and Productivity

Scientists at Colorado State University (CSU) are examining the impact of a variety of vertebrate and invertebrate herbivores on plant metabolism and productivity, seed production, and

community structure in order to obtain an in-depth understanding of consumers as regulators of ecosystems. The team, headed by James K. Detling of the Natural Resource Ecology Laboratory at CSU, includes Carlos A. Bonilla, Department of Physiology and Biophysics; John L. Capinera, Department of Zoology and Entomology; and Cleon Ross, Department of Botany and Plant Pathology.

The group, which is particularly interested in the response of plants to herbivore feeding, is examining the idea that herbivores serve not only as "mowing machines" but also as "innoculators" of salivary biochemicals. These salivary biochemicals seem to act as plant growth regulators, causing a series of metabolic changes that facilitate more rapid regrowth than that following mechanical damage alone.

Laboratory bioassays of a variety of vertebrate and insect salivas indicate that several may contain plant growth regulators. This initial screening is being checked by studying whole-plant response. Blue grama grass (*Bouteloua gracilis*), the dominant grass of the North American shortgrass prairie, is being studied intensively. Blue grama grass appears especially well adapted to grazing since it evolved under considerable grazing pressure from a variety of herbivores, including the North American bison and several insects. The grazing process is simulated in the laboratory by clipping blue grama plants and then adding saliva to them. After 10 weeks those plants that received this "light grazing treatment" increased total biomass by 13 percent over controls that were not clipped.

Although the immediate effect of grazing is a 60-percent reduction of photosynthesis in the remaining shoots, photosynthesis capacity recovers rapidly. In 3 days it ranges from 21 to 33 percent greater than unclipped controls. This higher level of photosynthesis is retained over a 10-day period. What is happening is that clipped plants allocate over one-half of the material produced in photo-

synthesis to construction of new photosynthetic tissue, whereas control plants allocate less than one-third. The blue grama response to grazing, then, is rapid reestablishment of its carbon-gain capacity at the expense of root growth. At least for a time, grazing increases metabolic growth response of the plant, which increases plant production above ungrazed controls. As grazing intensity increases beyond an optimal level, however, plant production declines.

The laboratory results were confirmed in field studies in nearly pristine prairie and in agricultural crops. Initial results indicate that herbivores have a larger and different impact upon the prairie than previously imagined. Related work has shown that field corn ears that had been damaged to simulate bird and insect attack exhibited a considerable amount of compensatory growth following damage; previous experiments suggested that protein content increased as well.

The Relationships of Flightless Birds

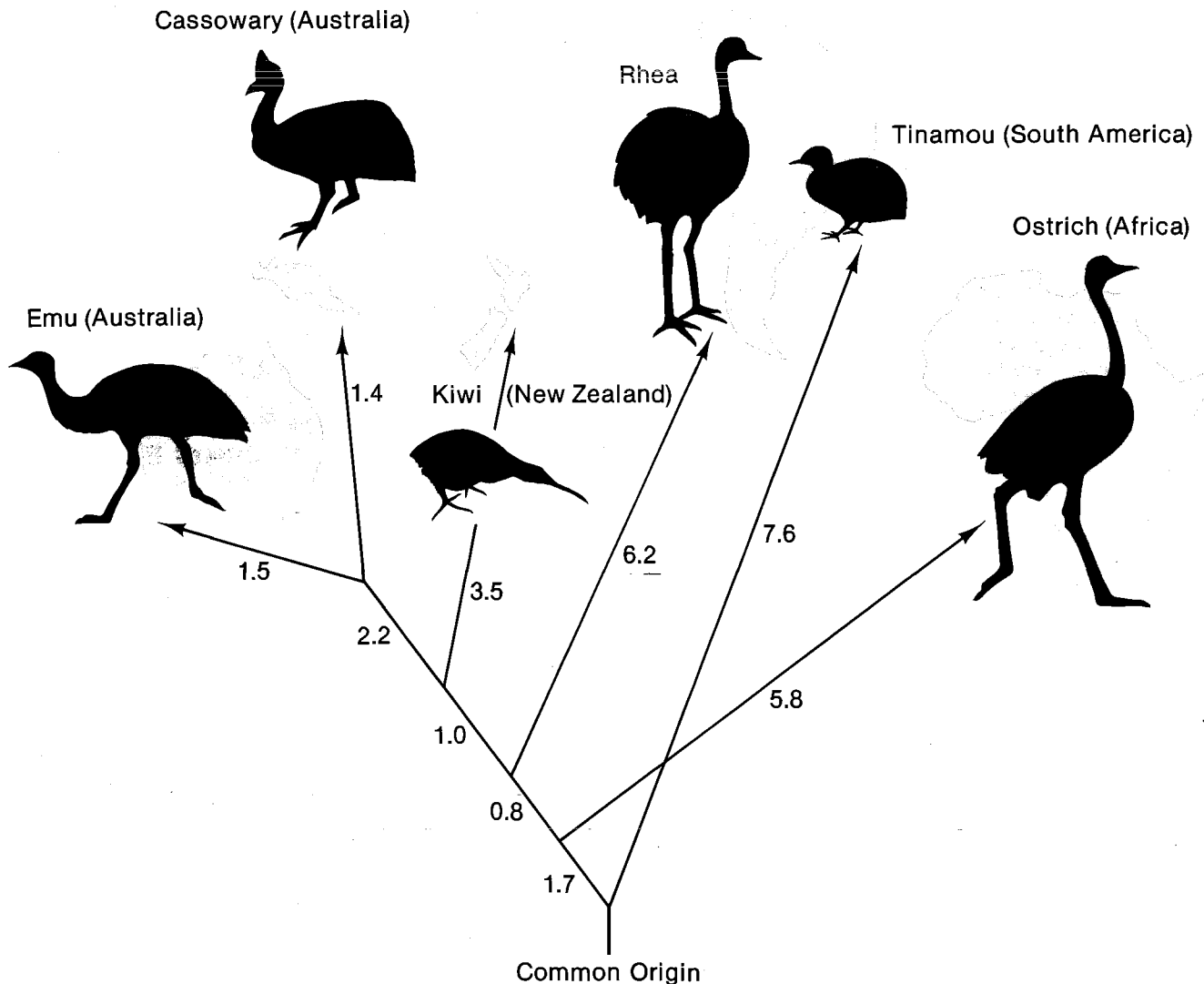
The living ratite (flightless) birds include the ostrich (*Struthio*) of Africa, the two South American rheas (*Rhea*), the emu (*Dromaius*) of the Australian plains, the forest-dwelling cassowaries (*Casuarius*) of New Guinea and northeastern Australia, and the three species of kiwis (*Apteryx*) of New Zealand. The relationships among these flightless birds and between them and the groups that fly—especially to certain neotropical species (the tinamous)—have been debated for more than a century.

The present geographical isolation of the southern continents from one another and the numerous anatomical differences among the ratites have been used to argue that each of the groups had a separate origin. But flightless birds share structural and behavioral characteristics and common parasites, which suggests a common

ancestry. The fossil record has been of little help in resolving the controversy since the evidence is inconclusive. The generally accepted theory of continental drift suggests that the ratites probably reached their present locations on the fragments of the protocontinent of Gondwanaland. Their genetic divergence, therefore, may be expected to reflect the history of the land masses upon which they now live.

Charles G. Sibley and Jon E. Ahlquist at Yale University are comparing the sequences of units of the genetic material of the ratites with one another and with that of many other groups of birds to assess their similarities. The technique they are using takes advantage of the fact that DNA is a double-stranded helix of complementary chemical units called nucleotides. The two strands of the DNA molecule can

be separated ("melted") by heating the DNA in solution to a temperature that will rupture the chemical bonds between the base pairs. Upon cooling, the complementary bases reassociate randomly, and a new double-stranded molecule forms. This property of "sequence recognition" permits DNA's from two different species to be mixed together, melted into the single-stranded condition, and allowed to



Phylogenetic tree. A new technique that compares the similarities between DNA molecules (the carriers of basic genetic information) of different organisms gives a measure of how closely they are related—i.e., at what point they diverged from a common ancestor. Applying the technique to the living flightless birds (and to the similar-appearing flying tinamous) leads to this proposed relationship, which would generally be expected if populations of birds had become separated by the breakup and drifting apart of continents. (The numbers represent relative differences in DNA.)

form "hybrid" molecules as they cool. The temperature required to melt the hybrid molecules is then determined and compared with the melting temperature of control DNA samples. The temperature difference is used as a measure of the similarity between the nucleotide sequences of the two species and, hence, as an index of their genetic similarity or, conversely, their divergence.

Further, by labeling the DNA of one species with radioactive iodine, scientists can measure the amount of hybridization that has occurred between the labeled species and each of the others. After these hybrid combinations (ostrich x ostrich, ostrich x emu, ostrich x rhea, etc.) have been incubated to permit reassociation, the frequency distribution of radioactivity for each hybrid can be plotted and the modal temperature for reassociation determined. A homologous hybrid (for example, ostrich x ostrich) has a modal value close to 85° C, while the heterologous hybrids (for example, ostrich x emu) have a lower modal value. This reflects the reduction in base-pair complementarity resulting from the genetic differences acquired since divergence from a common ancestor. The modal temperature difference between the homologous hybrid and that of a heterologous hybrid (called the delta mode) is used as a single number comparison. Delta mode values up to about 2.5 are usual for species of the same genus and up to about 9.0 for species of different genera of the same

family. Values from 10 to 15 denote members of different families in the same order, and above 15, members of different orders. In other words, these numbers can be used as indicators of species divergence, as expressed in a phylogenetic tree.

After comparing the five ratite genera and the tinamou genus *Nothoprocta*, in all possible combinations, Walter M. Fitch at the University of Wisconsin was able to generate a phylogenetic tree of ratites. Essentially the same tree was produced by a computer program based on a different procedure developed by James S. Farris at the State University of New York at Stony Brook. These comparisons indicate a close relationship between the kiwis of New Zealand and the emu and cassowaries of Australia and New Guinea. The pattern of phylogeny presented by the DNA data is reasonably consistent with the history of the breakup and drift of the Gondwanaland fragments. This agrees with other biochemical evidence, but it conflicts with both anatomical evidence and electrophoretic comparisons of proteins by Sibley and Ahlquist. These differences cannot yet be fully resolved because precise fossil dating to calibrate the delta mode scale is lacking. In addition, it is not certain that avian lineages evolve at the same rate. The innovative use of powerful techniques from molecular biology, such as DNA x DNA hybridization, will provide further insight into crucial phylogenetic and evolutionary issues.

accommodate competing goals.

Among recent developments in economic theory, the "rational expectations" hypothesis and new mathematical formulations of "bounded rationality" are of particular interest. The concept of "bounded rationality," discussed on the following pages, represents changes in basic economic theory that are being developed mathematically by Roy Radner at the University of California, Berkeley. The rational expectations hypothesis proposes that economic actors use all available information and anticipate future prices and demand in much the same way that an econometrician forecasts these quantities. Decisions based on these anticipations are rational in the sense that they are the best possible. In a recent analysis of unemployment and output, Robert Barro at the University of Rochester concluded that in the United States since 1946 unanticipated growth in the money supply had a notable impact on unemployment and output, but anticipated growth had much less effect. Current research is exploring factors that influence the capability of economic actors to adapt their behavior to such anticipations (e.g., long-term contracts) in an attempt to understand why the economy does not change precisely in accord with the implications of the rational expectations hypothesis.

Research in geography and regional science pertains to decisions related to the location of industries, choice of residence, and other interrelated choices that have implications for the redistribution of population, the growth and decline of cities, and shifting patterns in the use of land. The recent change in the long-term trend toward increasing population concentration in industrial societies is confounding our use of earlier models. Daniel Vining at the University of Pennsylvania has shown that the 60-year trend toward increasing concentration in the population has been reversed since 1970. His analysis, which indicates that this is not simply a

Social Sciences

A pervasive feature of current social science research is a focus on decision-making. In economics, for example, the traditional mode of analysis builds on constrained maximization models of decisionmaking. By exploring the impact of changing constraints, economists examine how different market

structures, changing regulatory mechanisms, or shifting prices affect decisions. These economic models are moving in the direction of increasing complexity and realism, especially as they attempt to handle decision-making under conditions of uncertainty and as they are elaborated to

result of wider dispersal around metropolitan centers, suggests fundamental changes in the pattern of decisions about the location of industries and the choice of residences. Current research is clarifying the reasons for such changes.

Both sociologists and political scientists explore decisionmaking by individuals. For example, factors influencing decisions to continue formal education beyond high school or to vote in particular ways have been examined in some detail. Other studies examine how organized collectivities such as communities, governmental bureaucracies, and voluntary associations make decisions. The analysis of decisions and the prediction of decision outcomes is found to be heavily dependent on the distribution of authority and power, communication and interdependence networks, and coalition formation. The basic processes underlying these factors are being assessed in current research. Through the use of public-choice models, mechanisms by which collectivities allocate resources for public goods also are being examined.

The social science research supported by NSF brings the tools of science to bear on the systematic analysis of social institutions and social arrangements in a disciplined search for basic principles. The phenomena that such principles must encompass are complex, but social science research is making progress toward developing a body of general, comprehensive, and empirically verified principles describing how social systems work, change, and affect the lives and well-being of individuals.

Organizational Change and Decisionmaking

New models of decisionmaking emphasize the costs and limitations of relevant information and the necessity for decisions to proceed under conditions of uncertainty. These new models also recognize that organizations

pursue competing, imperfectly articulated, and sometimes conflicting goals rather than a well ordered hierarchy of goals and objectives.

Pioneering work on mathematical models of rational decisionmaking under conditions of limited information is being conducted by Roy Radner at the University of California, Berkeley. His finding that under certain conditions the demand for relevant information will not be a continuous function of its price suggests a need for fundamental changes in basic economic theory. Radner's work captures many of the salient points of managerial dilemmas in that it deals with decisions in the context of achieving multiple goals. He has been able to derive the properties of certain plausible, but not necessarily optimal, behavioral rules under such conditions. He argues that managers in realistic situations do not formulate complete preference orderings but rather, seek workable strategies and act on that basis. Radner's mathematical work gives greater specificity to the concept of "satisficing" (choosing the first alternative that is good enough, as opposed to "maximizing") decisions and serves as the foundation for a developing theory of "bounded rationality." This theory has far-reaching implications for the analysis of decisions in organizational and economic contexts.

In other research on decisionmaking, Marshall Meyer at the University of California, Riverside, is examining factors that affect organizational growth and efficiency. His empirical work is based on 1966 and 1972 data describing 229 municipal finance agencies. Meyer reasoned that initial conditions would be predictive of subsequent changes and assumed that pressures for organizational change would be greatest in agencies where the demand was greatest. Accordingly, he focused on factors that increase or diminish the relationship between the initial size of the city

government and on subsequent changes in organizational size and/or modernization of procedures (for example, automation).

Meyer found that changes in leadership influence the extent to which organizational change reflects demand; agencies with stable leadership grew without regard to demand, but agencies with turnover of leadership changed in response to the size of city government. This suggests that change of leadership is a mechanism for influencing organizational decisions that affect growth and efficiency in response to external demand.

The range of tasks being done (e.g., accounting and auditing only versus those functions plus personnel, data processing, and program evaluation responsibilities) also affected the degree to which agency change was responsive to demand. This indicates that multiple goals, while potentially leading to managerial dilemmas, also create new avenues for external influence on the decisions of organizations. In his continuing research Meyer is exploring other, more direct measures of demands on organizations and assessing the conditions that influence how organizations respond.

These two lines of research—the development of more realistic models of decisionmaking and the empirical exploration of factors that influence organizational change—represent two developing areas of inquiry that are providing insights into basic processes in the behavior of complex organizations.

Efficient Resource Allocation

A central theorem in contemporary public finance is the inability of decentralized market or voting institutions to determine optimal public choices. This allocative inefficiency derives from the so-called free-riding problem associated with decisions on public goods, such as public television, where

one individual's consumption does not diminish that of another. If each participant's allocation of cost for the "public good" is determined by his stated willingness to pay, then he will have an incentive to understate his demand, thus gaining an advantage over other citizens who must carry a larger burden of the cost. The consequence of this free-riding behavior for society, evaluated in terms of individual preferences, is the systematic underprovision of public goods.

This inevitability of social waste in a decentralized economic environment has recently been questioned in a series of penetrating theoretical papers. The dominant theme of the new theoretical work has been the search for strategy-proof incentive structures to induce participants in decentralized markets to reveal their true willingness to pay for public goods.

Theodore Groves, John Roberts, and John Ledyard at Northwestern University have developed a set of institutional rules, rewards, and penalties that yield optimal levels of public goods. Basically, they start with the

traditional general equilibrium model of a competitive, private ownership economy and append to it an explicit procedure for determining consumers' demands for public goods and the corresponding tax burdens. Under their scheme, the taxes set by the Government and the allocative rules for determining the levels of public goods are structured in such a way that it is in the consumers' self-interest to reveal their true demand or evaluation of public goods. Participants indicate the desired level of public services, knowing the formula that determines their own payments, given their own and others' bids. At equilibrium an optimal allocation results, in which all mutually advantageous transactions have been made and no one can become better off without clearly depriving someone else.

Since the analysis is conducted in static general equilibrium terms, it is not practical to implement the proposed mechanism directly. The next logical step in the theoretical development of the mechanism is to formulate an explicit adjustment process that will

elucidate the dynamic path by which an equilibrium is reached.

In response to this need, Vernon Smith at the University of Arizona developed an adjustment process that has been tested in a number of small group experiments. His adjustment procedures incorporate the Roberts-Groves-Ledyard incentives mechanism and rapidly lead his experimental groups to the optimum at which no individual can increase self-satisfaction without adversely affecting someone else. These experiments and other studies of alternative incentive systems show that decentralized processes, which lead to optimal allocations, do exist for the provision of public goods. Moreover, Smith reasons, if we know a few such processes there must be others—some better, some worse, some cheaper, some dearer. These remain to be investigated. The next research frontiers, to determine the practicality of alternative institutional arrangements and to gauge the potential gains in efficiency from their adoption, are already being probed.

rently six separate but correlated activities aimed at assisting institutions in providing quality science education programs at all educational levels. The emphasis in all of these programs is to expand opportunities for participation to all types of institutions, especially those colleges with limited resources and experience in dealing with NSF.

Comprehensive Assistance to Undergraduate Science Education

The primary objective of the comprehensive assistance to undergraduate science education (CAUSE) program is to strengthen the undergraduate science education components of 2-year and 4-year colleges and universities. This will improve the quality of the Nation's science education at the undergraduate level and will enhance the capability of institutions for self-assessment, management, and evaluation of their science programs.

The 73 recipients of 1978 CAUSE awards included 20 2-year colleges, 34 non-Ph.D.-degree-granting institutions, 17 Ph.D. institutions, and 2 consortia. The projects reflect each institution's unique efforts to improve undergraduate science education.

For example, Queensborough Community College in New York will improve astronomy education through the development of an astronomy laboratory manual, the construction of an on-campus observatory, student-oriented research and astrophotography, and the development of alternate learning resources for home-capped.

In Oklahoma a consortium project including Oklahoma State, Central State, and Phillips Universities will, through contacts with regional industries, businesses, government agencies, and private firms, develop a case-study applied mathematics course for use by various educational institutions.



CAUSE. Two projects to upgrade the quality of undergraduate science education: (Above) A solar-heated greenhouse was built at Blue Mountain Community College (Pendleton, Oregon) to strengthen a plant science course sequence; (Below) A freshman at John A. Logan College (Carterville, Illinois) uses new computer equipment to learn BASIC computer language.



Faculty at the University of Florida will develop 125 modules for 18 psychology laboratory courses. The modules, using computer simulation of experimental work, television technology, and "hands-on" approaches, are expected to directly or indirectly affect the learning of some 10,000 students each year.

Through faculty training, computer research consolidation, and the development of computer-oriented course materials, Reed College in Portland, Oregon, will improve instruction in nine science departments, spanning mathematics and the natural and social sciences.

Undergraduate Instructional Improvement

The undergraduate instructional improvement program includes local course improvement (LOCI) and instructional scientific equipment (ISEP) programs. The common purpose of these small grants programs is to enable institutions to respond rapidly to relatively small-scale undergraduate science instructional problems and to enhance science teaching vitality by encouraging science faculty to pursue imaginative ideas in upgrading their instruction.

Projects may focus on any undergraduate instructional activity in science, including courses intended for science majors, nonscience majors, those preparing specifically for careers as teachers of elementary and secondary school science, or students preparing for technological careers. Awards go to widely differing types of public and private institutions, including the undergraduate components of universities, predominantly minority institutions, 2-year colleges, and 4-year liberal arts colleges.

Local Course Improvement

LOCI awards stimulate rapid introduction of the results of scientific and

educational research into the undergraduate curriculum and provide science faculty with the opportunity to develop teaching innovations. In fiscal year 1978, 135 awards were made. The resulting course development projects emphasized such activities as: the introduction and application of micro-processing computer technology, the development of teaching modules for self-paced instruction, the addition and restructuring of laboratory components, and the design of new audio and/or visual systems for conveying course content. Awards were made to individual science faculty or small groups of science faculty at 122 colleges (2-year and 4-year) and universities in 43 States. The maximum award was \$25,000, and all awards required an institutional contribution.

At the State University of New York at Oneonta, a LOCI project will develop a course to provide students with experience in interpreting satellite imagery of the Earth's surface in digital form, using the computer and quantitative techniques. An understanding of this technology will be applied to land and resource management issues.

A LOCI project at the College of St. Thomas, in St. Paul, Minn., will develop computer-based modules for teaching political science research methods. The modules, which will incorporate interactive and logic capabilities of the computer with graphics capabilities of films and slides, will provide immediate feedback to students as they are guided through the steps of the research process in a self-paced series of exercises. Increased understanding of and receptivity to political science as a social science is an anticipated outcome of the project.

Academically and economically disadvantaged students from the inner city will benefit from a LOCI project at the Los Angeles Trade and Technical College, where a set of video tapes covering basic laboratory skills in the biological sciences will be developed. Tapes will be available for student use

both in the laboratory and in the learning resource center.

"Computer Ethics," a LOCI project at Rensselaer Polytechnic Institute, will bring together mathematicians, computer scientists, and philosophers to design new course materials on computer privacy, computer theft, and other ethical issues related to automation and computer technology.

Instructional Scientific Equipment

These projects implement improvements in science instruction through the acquisition of new laboratory instruments and other instructional equipment. The objective is to provide relevant "hands-on" experience for undergraduate students in science and engineering laboratories. In fiscal year 1978, 352 awards were made to 281 institutions. In each case the Foundation grant—a maximum of \$20,000—was matched locally by at least an equal amount of institutional funding.

Nicolet College and Technical Institute at Rhinelander, Wis., will install two controlled environment chambers with accessory equipment. Students in ecology, biology, zoology, and botany courses will be able to grow and maintain living organisms within different environmental conditions. Thus, students will be able to observe directly the effects of the various air, water, and soil conditions that they now learn about and measure in other courses.

A grant to the University of California, Santa Barbara, provides matching funds for computer-compatible psychology laboratory equipment. Thus, the data from experiments can be relayed to the campus computer center and processed immediately. The result will be that students can see the outcome of experiments at once, without proceeding through extensive calculations or waiting while data are hand-carried to and from the computer.

At the Georgia Institute of Technology, an undergraduate environmental

monitoring laboratory is being equipped so that engineering students can be trained to investigate and measure parameters used in the analysis of the environmental impacts of selected engineering activities.

At the University of Nebraska, laboratory courses in food chemistry are being strengthened by the purchase of a gas chromatograph and an infrared spectrophotometer that will be linked to provide highly sensitive analytical capabilities. Such substances as lipids, fatty acids, food pigments, and flavoring compounds are of increasing concern to our food industry. More rapid, accurate, and reliable detection and measurement of such food materials will now be possible for students who have been trained in the use of these advanced analytical instruments.

Information Dissemination for Science Education

The purpose of this small grants program established in fiscal year 1977 is to provide opportunities for school administrators, subject-matter specialists, teacher-leaders, school board members, and other decisionmakers in State and local school systems to obtain information needed to examine and evaluate instructional materials and practices prior to selection.

Thirty-four awards in fiscal year 1978 for conferences and workshops enabled such school decisionmakers to become familiar with the large variety of science instructional materials, practices, and technologies currently available for use in elementary and secondary schools. In some projects information on current research results in pre-college science and mathematics education was presented to participants along with their potential classroom applications. The following projects illustrate those supported.

Regional conferences in Colorado, Idaho, Nevada, New Mexico, Utah, and Wyoming were held for secondary

school leaders under a grant awarded to Arizona State University. These conferences acquainted educators with Jean Piaget's ideas of intellectual development and their implications for science teaching. Chicago State University arranged conferences in the Chicago metropolitan area at which information was shared on research into the use of programmable calculators in pre-college mathematics and science education. The discussions included information about calculator hardware and commercially available curriculum materials.

Queens College of the City University of New York conducted a program for secondary school decisionmakers in the New York City area. The project focused on analysis and critical review of social studies material in anthropology, sociology, psychology, political science, and economics for use in secondary schools. WICAT, Inc., of Orem, Utah, arranged a conference in Salt Lake City targeted at education decisionmakers from eight Rocky Mountain States. Nationally recognized leaders made presentations on the use of such recently developed technologies as microcomputer, video disc, and video tape for science education purposes.

Minority Institutions Science Improvement Program

The primary purpose of this program is to effect long-range improvement in science education at institutions with predominantly minority enrollments. NSF supports science improvement projects at 2-year and 4-year postsecondary institutions whose enrollments are predominantly American Indian, Alaskan Native, Black, Mexican American, Puerto Rican, or other ethnic minorities who are underrepresented in science and engineering. Program objectives are to increase the number of minority students graduating with majors in the

sciences, mathematics, or engineering; to improve the quality of preparation of these students for graduate work or careers in science; and to improve the competitiveness of minority institutions for other Federal funding programs.

A total of 27 awards, including 3 small design grants to assist institutions without formal planning capabilities in the development of long-range science improvement plans, were made in fiscal year 1978. The awards encompass a range of activities. For example, the Highland Park Community College in Michigan will develop a Science Learning Center to provide individual help to students through the use of peer tutoring and audio-tutorial units developed by the biology department. In Washington State, the Lummi Indian School of Aquaculture and Fisheries will strengthen the basic science offerings in its 2-year curriculum to prepare students from various Indian tribes for fishery management and aquaculture responsibilities within their respective communities. The New Mexico Highlands University, in a 3-year plan, will strengthen laboratory programs in chemistry, restructure course offerings in biology, and improve its science course offerings through the development and use of video and audio materials.

Resource Center for Science and Engineering

The resource center for science and engineering program is a successor to the fiscal year 1977 minority centers for graduate education in science and engineering program. Its primary purpose is to increase participation in science and engineering by minorities and persons from low-income families.

The Foundation's fiscal year 1978 Authorization Act mandated the establishment of a single Resource Center. The center selected was to be geographically located near one or more population centers of minority

groups or low-income families and was directed to: (1) support basic research; (2) serve as a regional resource in science and engineering; and (3) develop joint educational programs with nearby pre-college and undergraduate institutions enrolling substantial numbers of minority students or students from low-income families.

A two-stage panel review process was used in the selection of the site of the single Resource Center. Twenty-six institutions or groups of institutions submitted proposals in stage one. Institutions submitting the six top-ranking proposals submitted revised proposals in stage two. Site visits were then made to the three institutions with top-ranking stage-two proposals.

As a result, Atlanta University received the first Resource Center award. Support was provided for a 4-year project in the amount of \$2,767,000. The university, in cooperation with the four undergraduate institutions in the Atlanta University Center, will engage in a number of activities to make its scientific resources more available to the Atlanta community and to a network of predominantly Black colleges in the Southeast. These activities will include short courses, summer science enrichment programs for high school and college students, a Saturday Science Academy for primary school children, and increased research opportunities for faculty.

process, to prepare people for new science-related tasks and problems, to translate scientific knowledge into a form that can be understood and learned, and to capitalize upon new insights into the way we learn. Both are needed to assure that all people will be able to cope with and enjoy the benefits of our technologically based society.

Development and research are not separate processes; they interact in complex ways. Development not only provides new curriculum materials and new organizations of the way we teach, but also generates new situations with new information for educational research to analyze and interpret. Research in science education gives us new ways of viewing the process of learning—the way we develop scientific skills and knowledge.

Science Education Development and Research

The quality of life depends in an increasingly large measure on science and its related technology. The health of science, in turn, depends on the quality of science education. Due to

rapid changes in science and society, science education must be continually modified through development and research. Both are needed to introduce new knowledge into the educational

Development in Science Education

The development in science education program (DISE) provides funds to originate, develop, and apply new ideas that hold promise for increasing the quality and diversity of science knowledge at any educational level and for any group of learners—in school or out. Key approaches include the development, testing, and evaluation of new instructional materials or novel delivery modes. The latter include application of technology to the educational process in ways that increase quality and/or reduce costs.

Fiscal year 1978 was devoted to intensive program review and planning as well as to continued support of several major projects. The planning effort resulted in new guidelines for fiscal year 1979 in five areas of special interest: science for the early adolescent; improving access to careers in science; science, technology, and society; new knowledge and new skills—education for productivity; and technology as applied to learning.

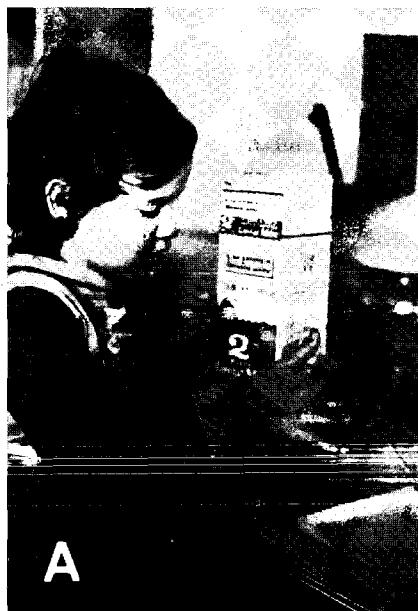
Fifty-three awards, totaling

Table 6
Science Education Development and Research
Fiscal Year 1978

(Dollars in Millions)

	Proposals		Awards	
	Number	Amount	Number	Amount
Development in Science Education	71	\$ 8.27	54	\$ 5.55
Pre-College Materials Development	11	2.40	9	1.32
Alternatives in Higher Education	24	4.18	22	3.12
Continuing Education for Scientists and Engineers	36	1.69	23	1.11
Research in Science Education	207	26.50	21	2.35
NIE/NSF Collaborative Research Program	64	7.23	11	0.50
Local Assessment of Science Education in the Two-Year College	70	1.57	38	0.46
Total	412	\$43.57	124	\$8.86

SOURCE: Fiscal Year 1980 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

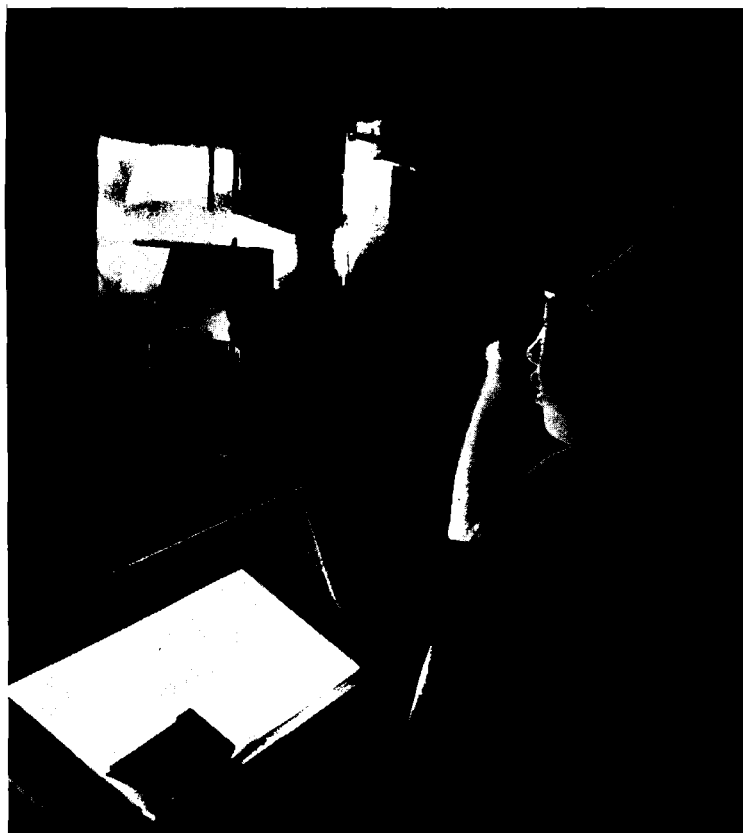


Science at home. Participants in the University of Idaho's project to use the family as an educational setting for elementary science education: (A) At the kitchen sink, a milk carton with holes and plugs at various levels is used to study pressure and flow rates; (B) Using an "Adviser's Guide," this mother works directly with her son in learning science at home; (C) Extending the laboratory to the neighborhood, these girls on skateboards learn some consequences of Newton's Laws of Motion.

\$5,405,000, were made in fiscal year 1978. Following are examples of DISE projects currently being supported.

Michael and Josephine Browne believe the family is an underutilized resource in education and that shifting some of the responsibility for learning out of the classroom and into the home will be both economical and effective. Last year this space was used to describe a prototype project, directed by Michael Browne at the University of Idaho, to develop a family-oriented approach to science education for children in kindergarten through eighth grade. In their "Family-Oriented Science Study for Elementary School Children," the Brownes are developing elementary science materials for children to use at home, in a family setting, with parents acting as advisers. Using the instructor's manual developed in the project, the teacher holds monthly evening workshops with parents to review the topics under study. Parents also receive manuals to assist them in encouraging the home science studies, and each child is given an "investigator's guide."

This year it can be reported that reactions to the initial physics and biology units now being tested are enthusiastic. Parents have a clear idea of what is expected of them and are willing to spend time helping the children with science studies. Since present "back to basics" trends leave little class time for science at the crucial elementary level, this type of home activity provides science education that might otherwise be missed; a stimulating exposure to science at an early age can be vital to later receptiveness to science education. Most important, the activity builds strong parent-child bonds and fosters a home environment conducive to learning. There are also important side benefits; parent involvement provides a subtle form of adult continuing education in science because parents learn along with children in an informal fashion. Since no expensive purchases are required the program stands a good chance of being



Science as sightseeing. Exhibits at the Exploratorium in San Francisco involve the visitors as participants in demonstrating physical phenomena. (Left) Fascinated with the "Bernoulli Blower," these two play and puzzle over why the ball always gets sucked back into the middle of the air jet. (Right) In the "Glow Box," this boy inserts various interference filters into the path of a beam of white light and, seeing the changes in color, learns that "white" light consists of many colors. (Photo at right by Susan Schwartzberg)

accepted by schools beleaguered by cutbacks in local taxes.

Beginning with an initial award in 1972 and continuing through 1978, NSF has provided about \$1 million to San Francisco's Palace of Fine Arts and Science Foundation for exhibit development by Frank Oppenheimer at the Exploratorium. This support has resulted in the development of about 75 percent of the Exploratorium's more than 400 exhibits.

Conceived by Oppenheimer to provide opportunities in science education that are difficult to achieve through school classrooms, books, or television, the Exploratorium opened its doors in 1969 and has grown to the point where its current annual attendance exceeds

half a million visitors, including 50,000 school children on scheduled field trips.

In the July 1972 issue of the *American Journal of Physics*, Oppenheimer described the philosophy embodied in his "playful science museum": "The roots of science frequently lie in sight-seeing. . . . Darwin, during the voyages of the *Beagle*, was sight-seeing, and after his return these sights led to the formulation of ideas that have fundamentally changed the way people view themselves and their relationship with nature. . . . In recent years, much of high energy physics, especially bubble chamber analysis, has constituted little more than a very elaborate form of sight-seeing. . . . We

are exploring various forms of museum teaching and learning in the Exploratorium, but our effort would be worthwhile even if it did no more than provide some good sight-seeing. . . ."

Oppenheimer and his associates have integrated science and art in the development of Exploratorium exhibits. Employing the design work of artists (through an "Artists in Residence" grant from the National Endowment for the Arts) and scientists, the exhibits illustrate beautiful and basic natural phenomena stressing either the esthetic approach of the arts or the analytic approach of the sciences. Exhibits are grouped to form coherent, interconnected sequences—

they lead the visitor into the domain of physics, biology, and mathematics. These exhibits are designed to be manipulated and appreciated by both children and adults at a variety of levels.

Must every continuing education course in science be developed independently by the institution offering it? Could this overwhelming duplication of effort be sidestepped by development of a system under which specialized teaching materials developed at one institution are easily obtainable by other institutions with the same needs? With support from NSF, a consortium of 19 major engineering schools—the Association for Media-Based Continuing Education for Engineers (AMCEE)—is exploring and developing mechanisms to answer these questions.

AMCEE works closely with industry, professional societies, and practicing engineers to determine needs in continuing engineering education and to provide information to member institutions. A key activity, development of an effective mechanism for the active exchange of teaching materials between member institutions, is implemented through a materials production and utilization committee, which manages a "revolving fund." This fund, provided by the Sloan Foundation, is used to assist any one of the member institutions to develop instructional materials that will be available for use at other institutions. Use charges, returned to the fund, are available for other materials development activity.

AMCEE headquarters are at the Georgia Institute of Technology,

which serves as the fiscal agent for the association. Charles R. Vail of Georgia Tech, corporate secretary of AMCEE, serves as project director. To ensure that its activities are responsive to the continuing education needs of the industrial community, the association's Governing Board works intimately with a nationally representative Industrial Advisory Board and with regional boards associated with each of the member institutions.

At Northwestern University, Mark Pinsky is developing an accelerated, interdisciplinary, 3-year bachelor's degree curriculum that focuses on mathematics, physics, chemistry, biology, geology, and astronomy, and includes theoretical, laboratory, observational, and computational training. Designed for the superior high school graduate who has achieved advanced



Broad science curriculum. An accelerated undergraduate degree program at Northwestern University gives superior students a multidisciplinary science education prior to specialization in graduate school. The program is characterized by student access to their own computer facilities and sophisticated laboratory equipment (left) and informal interaction with faculty (right). (Photos by Alice Snyder)

placement in mathematics, Northwestern's ISP (integrated science program) is entering its third year and will graduate its first class of students at the end of the spring quarter, 1979.

This project is expected to serve as a national prototype curriculum for giving undergraduates an overview of all the sciences and of mathematics in terms of first principles, the state of the art, and problems at the forefront of science. Pinsky says that ISP graduates will possess fundamental understanding of science and experience with a wide range of techniques and materials; this should prepare them for graduate studies leading to careers as professional scientists.

In the future, there will be an increasing need for scientists who have the broad background necessary to solve important scientific and technological problems that require comprehensive and multidisciplinary solutions. Students trained in an integrated science program are expected to be more flexible in approach, better able to use a variety of techniques drawn from many scientific fields, and more able to work collaboratively than students trained in traditional disciplinary programs.

Research in Science Education (RISE)

Now in its second year, long-range research planning was initiated to identify important issues in science education. Eighty leading scientists, science educators, and educational researchers prepared reports on the present and future of science education, formulated a basis for research planning, and made recommendations for a long-range program of research. In addition, out of 207 proposals received, 21 grants were awarded totaling \$2.35 million. Priority was given to the study of motivation and learning of science by early adolescents (ages 10-15 years), measures of effectiveness of science education, attitudes

toward science with special emphasis on minorities and women, and microcomputers in science education. The following are examples of new and ongoing awards.

Herbert Simon at Carnegie-Mellon University, winner of the 1978 Nobel prize in economics for research done a number of years ago on decision-making processes, is trying to find out why such a high percentage of students are unable to solve simple problems in physics and mathematics, even after long periods of formal study. His research team of physicists, psychologists, and computer scientists is studying step-by-step verbal accounts of the processes used by "naive" as well as "expert" subjects as they attempt to solve physics and math problems. These data will be used to formulate explicit models of competence in a variety of topics in elementary physics and mathematics. Based on these models, computer programs will be designed that replicate the variety of observed students' problem-solving processes. This approach requires a detailed definition of every step in the problem-solving process, thereby uncovering steps that would otherwise remain implicit. It also enables researchers to simulate and, it is hoped, understand student errors by intentionally inserting "bugs" or faulty procedures into the programs.

This project is funded under the joint National Institute of Education/National Science Foundation inter-agency program (established this year) of research on cognitive processes and the structure of knowledge in science and mathematics. It is believed that projects such as this will help us to understand the nature of interaction between subject-matter knowledge and general problem-solving skills in learning physics and mathematics. This would be of considerable value to teachers and textbook authors, who now must proceed largely on personal intuition and experience.

In three related projects, Norris Harms of the University of Colorado,

Irving Morrissett of the Social Science Education Consortium, Inc., in Boulder, Colo., and Alan Osborne of Ohio State University are attempting to make research more accessible by synthesizing and analyzing existing data on the goals of science, social science, and mathematics education in grades kindergarten through 12. They will compare their conclusions with research on the current status and results of secondary science education, especially that of three recently completed NSF studies. The differences that emerge between the desired and actual states will determine an agenda of needs and recommended actions that will be broadly communicated to policymakers, educators, and the public.

In the 1960's the U.S. Government looked to technology already in the home—television—to help bring about a national revolution in education. The power of this ubiquitous technology system was seen in the impacts of shows like "Sesame Street." Over the next 5 years it is anticipated that a new interactive technology, the personal computer, will find its way into the same American homes, creating another educational opportunity. Ira P. Goldstein of the Massachusetts Institute of Technology is trying to exploit this opportunity by developing a theory and building a prototype system to experiment with the ability of such computer programs to convey important intellectual skills in mathematics and science. Goldstein says that from the user's perspective the computer can, for example, provide advice regarding the appropriate strategy and tactics to win computer games. From the educational perspective, however, such advice can provide an opportunity to tutor the user in the basic mathematical and scientific knowledge that the games employ. Although the computer hardware needed for games and computer-based tutoring is expected to continue to drop in cost, the software technology and the related educational and psychological theory for

the design of such computer-based tutors does not yet exist. Goldstein will use his NSF grant to build a foundation to help remedy this situation.

Janan M. Hayes is closely examining the changing composition and needs of the student body at American River College in Sacramento, Calif., and the reactions of faculty to these changes. The results of his surveys and computer analyses will be used as a basis for faculty discussion and recommendations for the future of the college's

science education program. This is one of the projects funded under the two-year college local assessment in science education (TYCLASE) program, which is intended to identify the strengths and weaknesses of 2-year college science programs and provide a rational context for institutional planning and changes. A related program, two-year college comprehensive assessment in science education (TYCCASE), is producing a nationwide needs assessment of science education in these institutions.

Student-Oriented Programs

Student-oriented programs provide challenges and opportunities for research and study not usually available to high school and undergraduate students and for those who have demonstrated high science potential but whose training has been deficient. The programs give students more responsibility for planning and carrying out their own learning activities, and thus demonstrate their capacity to be motivated by this measure of independence.

Scientific Personnel Improvement

The objectives of these programs are to identify and encourage scientific talent; to assist in maintaining high standards and quality in the training of students and professionals in the sciences; and to stimulate more participation in the sciences by minorities, women, and the handicapped.

In meeting these objectives, the Foundation supports programs focused on four target populations: (1) high school and undergraduate students, (2) minorities, women, and the handicapped, (3) graduate and postdoctoral students, and (4) teachers of science at both the college and pre-college levels.

Table 7
Scientific Personnel Improvement
Fiscal Year 1978

(Dollars in Millions)

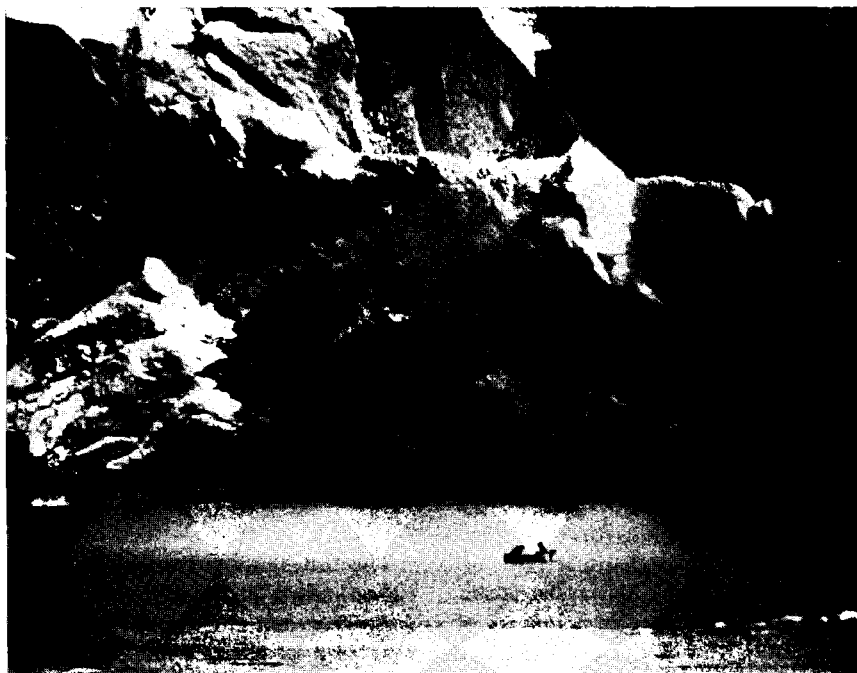
	Proposals		Awards		Number of Individuals Supported
	Number	Amount	Number	Amount	
Fellowships and Traineeships	6,494	\$ 59.66	1,653	\$14.16	1,678
Graduate Fellowships	4,978	36.34	1,456	11.04	1,456
Postdoctoral Fellowships	1,070	14.49	130	1.76	130
Minority Traineeships	446	8.83	67	1.36	92
Student-Oriented Programs	1,041	15.86	343	5.10	6,670
Student Science Training	304	6.11	143	2.20	5,107
Undergraduate Research Participation	565	7.35	135	1.98	1,059
Student-Originated Studies	172	2.40	65	0.92	504
Minorities, Women & Physically Handicapped	238	6.31	68	2.31	20,639
Faculty Improvement Programs	1,686	38.68	413	10.14	18,751
Pre-College Teacher Development	709	20.17	269	6.76	15,324
College Faculty Short Courses	20	2.17	17	1.06	3,300
Science Faculty Professional Development	957	16.34	127	2.32	127
Total	9,459	\$120.51	2,477	\$31.71	47,738

SOURCE: Fiscal Year 1979 and 1980 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

Student Science Training

In this program, university research scientists are involved directly with groups of talented high school students. Of the 150 projects for 11th and 12th grade secondary school students supported in 1978, 83 were designed for the educational development of high ability students with excellent training and 67 were designed for students with demonstrated high potential but limited educational opportunities. These latter projects focused on students with inadequate facilities or instruction who were located in the inner cities or in isolated rural areas and who belonged to educationally disadvantaged populations. Projects ranged from intensive programs in a single science discipline to multidisciplinary activities in oceanography, operations research, textile engineering, urban geography, and environmental assessment. Two projects were designed and operated specifically for the physically handicapped. The following are examples of projects funded.

An academic year project at Portland State University involved 25 high school students who traveled throughout Oregon observing and talking with groups representing Indian, European, and Oriental settlers in the area. The students also carried out in-depth research projects on topics related to Oregon's heritage, and many of these



Student Science Training. Two of the summer 1978 projects for high ability high school students: (Above) In Mendenhall Lake in the Juneau Icefield, Alaska, students under the direction of the Foundation for Glacier and Environmental Research gather data on noise (seismicity) relating to glacier movements (photo by Robert A. Asher). (Below) In an engineering project at the Illinois Institute of Technology, students construct circuitry for a model traffic control system.



are being placed in the Portland State University library as part of the social science holdings. As a direct result of the project a new undergraduate course, an in-service course for teachers, a course for students ages 11-15, and a course for adult members of local cultural/ethnic organizations are being initiated in the region.

A Wayne State University project focused on the engineering challenges to the automotive industry. The project involved 32 participants and utilized lectures, laboratories, field trips, and individual research. Student research projects included the effects of driver-controlled variables on the fuel economy of a car and the effects of various seat belt designs on the safety of a car's occupant in an accident. The faculty involved in the project are encouraging and helping the students to prepare presentations for their own high schools on their study and research.

Thirty high school students with limited educational opportunities, and primarily from minority groups, were given an opportunity at Louisiana State University to understand the analytical thought process and activities of engineering and to participate in engineering design projects. Many of the students, though the best in their classes in their rural schools, had never been challenged and were not aware of real-world technological problems. Places visited included NASA's Johnson Space Center, Texas Instruments, and the Louisiana Power and Light Company. Faculty and guest lecturers presented talks on careers in the various fields of engineering, job prospects, and requisite preparation, and students participated in project-design work in engineering fields of their choice.

Student-Originated Studies

This program encourages upper division undergraduate students to assume more responsibility for their own learning and to contribute directly to

the Nation's research effort on societal problems. In 1978, 65 student-originated studies projects were designed and carried out, with minimal faculty supervision, by 504 students at 62 colleges and universities. Studies were directed toward collection of data of particular and immediate use to civic bodies, governmental agencies, and the like, and ranged over a wide spectrum of topics.

For example, a team of ten students at the University of Pennsylvania developed a new approach to the problem of artificial heart implantation. The group completed and tested a mock circulatory system driven by commercially available solenoids linked to a syringe pump and a special series-wound electric motor for testing alternate low-density materials for windings and brushes. The team also examined a variety of dielectric materials in a search for more medically

effective techniques involved with artificial heart implantation. Tentative results are very encouraging.

At the University of Northern Arizona at Flagstaff, five students conducted chemical, biochemical, and biological tests of plants near a coal-fired generating station to determine the effects on surrounding soils and plants of this means of power production. Analysis centered chiefly around the native plant *Gutierrezia* for trace metals. Highly significant results are tentatively reported for correlations between time and concentrations of several trace elements in surrounding soils and vegetation, and are expected to suggest the need for further environmental control measures.

A team of ten students at the University of California, Santa Cruz, completed a study of natural resources of the Granite Mountains in an effort to provide information for land management decisions and a baseline inventory for future detailed land-use practice studies. The studies included geology, botany, zoology, and land-use

history. The information will be given to local planning agencies.

A group of five students at the University of Colorado at Boulder completed a study of rock stress conditions in an effort to accurately predict impending hazardous rockbursts. Approaching the problem from previous and current work of seismologists, and aided by personnel in the U.S. Bureau of Mines, the project team has made significant advances in the measurement of rock stress and the prediction of rockfall.

Undergraduate Research Participation

The undergraduate research participation program provides selected undergraduates in their junior and senior year with firsthand experience in the research process by enabling them to work full time with university science faculty or industrial scientists. Talented science students thus have a special opportunity to assess possible



Undergraduate Research Participation. (Left) At the University of Texas at Arlington a student works on calorimetric reactions of rhodium and iridium complexes. (Right) An electrical engineering student at Texas Tech University demonstrates a new kind of nitrogen laser to his faculty adviser.

career choices well before entering graduate programs. Among the 135 projects supporting a total of 1,059 undergraduates were the following:

At Grinnel College in Iowa, four students joined professors in ongoing research in chemistry, involving NMR (nuclear magnetic resonance), spectroscopy of metal complexes, electrochemistry of heme-protein derivatives, molecular weight measurements on giant DNA molecules, and biomolecular reactions of excited state complexes. Ten students at the Duke University Marine Laboratory at Beaufort, N.C., engaged in interdisciplinary research in marine biochemistry, membrane and environmental physiology, biomedical engineering, several aspects of oceanography, ecology, developmental biology, and applied environmental science.

Three projects allowed 24 students to take part in research in industrial settings. For example, at Macalester College in St. Paul six students studied computer applications, such as laser scans of coated films to monitor coating processes. These activities were conducted in the research centers of cooperating computer technology and other industries, including 3M, Honeywell, and Control Data in St. Paul and Minneapolis.

Minorities, Women, and the Physically Handicapped in Science

These programs develop and test methods to attract, encourage, and motivate the participation in science by minorities, women, and the physically handicapped. Activities include studies, workshops, and special training opportunities beyond those available in existing formal science education programs.

Minorities

Using the proven models of the student science training and undergraduate research participation programs,

the Foundation supported projects to motivate and train more minority students and provide them with the opportunity to study and do research in a variety of scientific disciplines. For example, at Texas Tech University ten participants are working with research faculty on projects in energy-related research, including: the development of computer-generated masks for use in optical data processors, which would reduce costs in information retrieval; the development of an electrostatic energy analyzer; and a study related to contrasts and clutter in aerial photography. Through these activities the participants will be better informed about the nature of scientific research and will be able to make more realistic career decisions.

Women in Science

Twenty-five workshops involving approximately 5,000 women students in colleges and universities were carried out in 17 States to provide in-depth information on careers in science and engineering. Considerable interest has been generated by the visiting women scientists project. This draws on the work experience of career women scientists, who also serve as role models to motivate girls in secondary school to continue studying science so they don't cut themselves off from a possible career in science. Over 600 women applied to serve as visiting scientists; 40 were selected to visit 110 high schools.

Six projects were to assist women with science degrees who are currently not employed in science or are underemployed in terms of their potential. On completion of special training to update their science backgrounds, these participants are prepared for entrance into graduate school or for direct employment in science.

Physically Handicapped in Science

Fiscal year 1978 was the second year of operation for the physically handicapped in science program. Six of the

projects directly involved handicapped students of science. Typical was an environmental research activity involving 20 high school students who participated during the summer at Marist College in Poughkeepsie, N.Y. They attended lectures, did laboratory experiments in water testing, performed parasitology studies on fish, and learned ecological sampling techniques. Another project modified a college general biology course for the visually impaired so as to use other senses, such as touch and sound, to augment or replace sight. Two conferences assessed the current state of science education for the handicapped and looked at ways to eliminate barriers in postsecondary education, and four workshops dealt with the generation of career information for the handicapped. All projects were designed to help facilitate the entrance of handicapped students into careers in science and science education.

Fellowships and Traineeships

Graduate fellowships and traineeships support a limited number of the Nation's most promising predoctoral science students. This assures a small but stable and highly talented input to the scientific personnel pool while also taking steps to improve the representation of certain minority groups in that pool. Postdoctoral awards support well qualified young scientists working on problems perceived as national needs.

Graduate Fellowships

By supporting full-time study toward graduate science degrees, this program accelerates the students' professional development toward becoming contributors to the U.S. scientific enterprise. In fiscal year 1978, 4,331 undergraduate science and engineering majors from throughout the country competed for 490 new 3-year graduate fellowships. In addition to the

students who won fellowships in this rigorous national competition, 1,439 other applicants were awarded "Honorable Mention" and cited as being highly deserving of support. This citation frequently assists applicants in acquiring other sources of funds and, thereby, indirectly aids their pursuit of graduate scientific study. New fellows, attending institutions of their choice, are joining a cadre of 1,140 other current NSF fellows.

Minority Graduate Fellowships

Initiated by Congress in fiscal year 1978, this new program operated in an experimental mode. NSF requested nominees from 80 institutions that had significant experience with minority science students. Review of the 72 eligible nominees resulted in the award of 43 fellowships to those judged most qualified. These 3-year fellowships may be used for advanced science study at any U.S. institution chosen by the student. Based on the experience gained, NSF developed and plans to use hereafter a national competition designed to draw upon the full pool of eligible minority students, independent of their institutional affiliation.

Minority Institution Graduate Traineeships

After an experiment in 1974, and in an effort to improve participation of minorities in the advanced levels of science, the minority institution graduate traineeships program became a regular offering in fiscal year 1977. In fiscal year 1978 the program expanded the target audience to include all institutions having more than 50 percent aggregate minority enrollment and offering the master's degree in at least one science, regardless of the number of graduate science degrees awarded in recent years. Twenty-three eligible institutions requested support for 341 trainees, and 50 3-year traineeships were awarded to specified science departments at 13 institutions. Grantee institutions appoint awardees to either full-time or part-time traineeships in

support of their entry to the advanced science personnel pool.

National Needs Postdoctoral Fellowships

In an effort to enhance the country's ability to deal with scientific problems of national importance, this program provides 1-year fellowship support for advanced study and research to promising young postdoctoral scientists and engineers. From among 928 applicants, NSF made 138 awards. All awardees showed high promise of advancing toward solutions to some of the complex problems we face today. For example, one fellow will study energy loss from electrical generators as one approach to making the Nation more energy-efficient. Another fellow is examining the use of sound waves to detect internal stress in metals, thus hoping to reduce the exposure of industrial workers to X-rays.

Faculty Improvement Program

The goal of the faculty improvement program is to enhance the competence of teachers so they may continue to provide high quality instruction in the sciences for their students. Participation in the 1978 programs was open to all individuals teaching science, mathematics, or social science in U.S. elementary and secondary schools, 2- and 4-year colleges, and universities.

Pre-College Teacher Development

In its second year of operation, this program continues to stress the improvement of the teachers' knowledge of the subject matter of science and to foster communication and cooperation between elementary or secondary school teachers and colleges and universities.

The distribution of the 15,324 participants by level of employment for the 1978 program was: 35.6 percent

elementary; 35.8 percent middle and junior high school; and 28.6 percent senior high. Of the 269 projects supported, a third were concerned with the interrelationship of science and society, and 22 focused on teachers of minority students. Activities supported ranged from a workshop in basic physics for upper elementary teachers to an in-service education project in political science for secondary teachers.

The Catholic University of America is offering a course for upper elementary teachers that seeks to provide exposure to principles of basic physics and to provide training in techniques to carry these principles into their classes. A unique feature of the course is the use of the Invent Room and Sound Studio at Capital Children's Museum, a new "hands-on" museum in Washington, D.C. It is basic physics come to life, with each principle isolated and concepts presented in tangible and dramatic form.

At Western Washington University a project for 25 junior and senior high school teachers from Idaho, Oregon, and Washington deals with a topic having major implications for the United States, the adoption of the 200-mile territorial water limit for the Nation in general and the Pacific Northwest in particular.

California State University, Northridge, offered 40 elementary teachers in grades four to six in the Los Angeles City Unified School District an opportunity to update and extend their knowledge of the subject matter of the social sciences by working with social scientists and social science education specialists.

College Faculty Short Courses

The college faculty short courses program introduces science faculty to the latest scientific developments so as to expedite their inclusion in undergraduate curricula. The courses consist of two intensive 2-day sessions and an intervening period of several weeks for individual work on a project related

to the course. Fifteen field centers host the lecturers, who move through a Chautauqua-type circuit from one center to another throughout the country.

The 1978 program supported the participation of some 3,300 college teachers in 52 different short courses that dealt with such topics as solar energy from an engineering perspective, mathematical modeling in the biological sciences, and the history of physical science. For example, David T. Tuma of Carnegie-Mellon University teaches a course in application of microcomputers to science education. Several areas in which microcomputers have potential for enriching science education are computation and simulation, interactive learning, controllers for experiments or processes, and data acquisition and reduction.

Reginald Vachon and John Goodling of Auburn University and Jeffrey Morehouse of Texas A&M University teach a course on solar energy from an engineering perspective. This course introduces the fundamentals of solar thermal energy utilization by using both analytic and experimental hands-on presentations, including the construction and testing of types of solar collectors. Interim projects include the testing and evaluation of solar collectors, measurement of solar insolation, and evaluation of thermal storage systems.

Science Faculty Professional Development Program

The objective of this program is to improve undergraduate science teaching in 2- and 4-year colleges and universities and thereby improve the capabilities of students in meeting employment opportunities. Awards were offered to college and university teachers to pursue research or study for 3 to 12 months at institutions of higher education or in industrial or other nonacademic laboratories.

Through this program a teacher of undergraduate students obtains new

insights into subject matter and gains new perspectives that are transmitted to the students.

Of the 957 applications received, the program selected 127 for award; 65 were for research in industrial or non-academic laboratories. While the overall percent success of applicants for the program was 13.3, that of minorities was 13.9 and of women 18.4. Applicants from 2-year institutions had approximately the same success rate as those from 4-year colleges and universities.

Activities varied widely. For example, one applicant, an organic chemist, wished to provide students of art and art history with an understanding of the materials with which they work, the nature of color and color modification, the chemistry of photography, the chemistry of conservation and preservation of artistic and historic objects, and the scientific methods used in the authentication and verification of art objects. To do this, the applicant affiliated with the Conservation Center of the Institute of Fine Arts of New York University.

Another program utilizes the equipment and expertise of personnel of the Goddard Space Flight Center to process and interpret remotely sensed imagery with three objectives in mind: (1) to compare the characteristics of aerial photography and satellite imagery for application to forest science and

related land-use undergraduate instruction; (2) to produce land-use maps and vegetative inventory data as illustrations of remote sensing application to problems existing in southern Illinois and the surrounding region; and (3) to ascertain the role of remote sensing in Southern Illinois University's education, research, and service commitments. The program will provide competency in the technical aspects of remote sensing and will enhance the application of these techniques in the instructional programs of several departments at this institution.

Another grantee has designed a program involving graduate-level course work, independent study, and research to improve his competence in the areas of thermodynamics and energy conversion and use. His independent study involves assessing the solar resource in New England and the technology of utilizing solar energy for residential heating and hot water. This teacher is particularly interested in the possibilities of retrofitting existing structures with solar energy and the feasibility of a semidetached combination solar and wood heating addition for residences. These activities will lead to the introduction of energy topics into the elementary and secondary science curricula and the development of an energy curriculum center in his institution's Energy Resource Center.

Science and Society

NSF's science and society programs are concerned with those issues that arise out of the changing relationship between the scientific and technical communities and the society of which they are a part. Its activities are based on the assumption that the health of both science and society requires: (1) an understanding of the increasingly

complex base of science and technology underlying matters of personal choice and public policy on which citizens must make decisions; (2) interaction between the ethical and social values and standards of society as a whole and of the scientific community; and (3) full and informed participation of scientists and citizens in the decisionmaking process.

Table 8
Science and Society
Fiscal Year 1978

(Dollars in Millions)

	Preliminary Proposals		Proposals		Awards		Number of Individuals Supported
	Number	Amount	Number	Amount	Number	Amount	
Public Understanding of Science	220	\$18.00	72	\$16.00	25	\$2.40	-0-
Ethics & Values in Science and Technology	200	15.00	66	5.70	19	1.29	30
Science for Citizens	709	20.18	261	5.80	71	1.67	33
Forums, Conferences and Workshops	400	14.00	77	2.50	21	0.61	
Residents and Internships	-0-	-0-	134	2.10	33	0.53	33
Planning Studies	309	6.18	50	1.20	17	0.53	
Total	1,129	\$53.18	399	\$27.50	115	\$5.36	63

SOURCE: Fiscal Year 1980 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

Science for Citizens

The overall goals of the science for citizens (SFC) program are twofold: (1) to make scientific and technical information and expertise available to citizens at the times and in the ways most useful to them; and (2) to increase the knowledgeable participation of scientists and citizens in resolving major issues of public policy that involve science and society.

In fiscal year 1978, its second year, the public service science residencies and internships program awarded 25 residencies to scientists and engineers and 9 internships to science and engineering students. These awards allow them to undertake up to a year's activities with citizen groups and other organizations in need of their expertise. Examples of the projects being undertaken by fiscal year 1978 residents and interns include a resident, working with the Navaho Nation and Colorado State University, who is studying the nutritional status of native Americans and conducting training sessions on health and nutrition policy for native American decisionmakers. Another resident is producing and moderating bilingual radio programs focused on

scientific issues in proposed State legislation for the Association of California Public Radio Stations. An intern is working with the Center for Local Self-Reliance and the Minnesota State Legislature to evaluate urban energy conservation programs and to encourage citizen participation in developing energy policies.

Some preliminary results from the fiscal year 1977 science for citizens forums, conferences, and workshops indicate that those projects were able to bring scientists and citizens together to shed light on and help resolve issues of public policy that involve science and technology. A number of publications are currently available from these first projects. The Citizen Involvement Network (Washington, D.C.), for example, has published *Retrofit '78*, the proceedings of a New England conference on community-focused home insulation and energy conservation programs. Another publication, *The Community Communications Workbook* of the Knoxville (Tennessee) Communications Cooperative, is intended to assist persons interested in understanding or undertaking community-based cable radio or TV services.

In 1978 the SFC forums, conferences, and workshops program supported 16 new projects, among which are a workshop, with radio coverage, held by the Turtle Mountain Community College on the forest ecosystem, so that tribal members can participate in the formulation of timber cutting policy on the Turtle Mountain Indian Reservation in North Dakota. The Public Resource Center (Washington, D.C.) is conducting a series of Appalachian community forums to look at the changing environmental and occupational health needs resulting from industrial expansion in the area. Northeast Louisiana University is establishing a Regional Utilities Information Center to hold workshops on energy-related issues, which will involve fuel suppliers, utility companies, regulatory authorities, and consumers.

As a new initiative in fiscal year 1978, the science for citizens program also awarded 17 planning studies grants to community groups, public interest science organizations, and educational institutions and service organizations. These grants are intended to help them develop stable organizational structures and processes (such as public service science centers or networks) that can provide timely and intelligible scientific and technical assistance to their communities. Examples of the fiscal year 1978 planning studies grants include a project where the Metrocenter Y.M.C.A., in collaboration with the City of Seattle, the People Power Coalition, and the University of Washington, is planning a Seattle Metropolitan Technology Assessment and Transfer Center to link area scientific and technical resources with citizen groups. In another, the Georgia Community Action Association will evaluate methods for providing technical advice on science- and technology-related policy issues to disadvantaged citizens in urban and rural areas, and will prepare guidelines for the establishment of a Citizens Technical Advisory Center. The Southwest

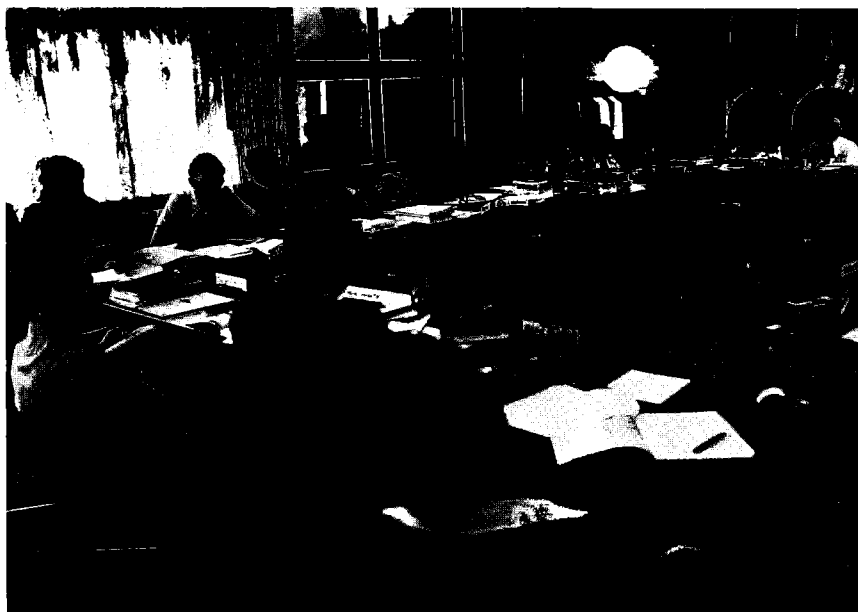
Research and Information Center is producing a model for a network of New Mexico organizations that can deliver scientific information to citizens to help them work with scientists in identifying and resolving public policy issues involving science and technology.

Ethics and Values in Science and Technology

The ethics and values in science and technology (EVIST) program is directed toward identifying, analyzing, and resolving the ethical and social dilemmas that arise in the work of scientists and engineers and in their interactions with citizens affected by their work.

An International Symposium on Social Values and Technology Choice, organized under the auspices of the U.S. Pugwash Committee and the American Academy of Arts and Sciences, was held in Racine, Wisconsin, in June 1978. The symposium brought together 35 scientists, scholars, and Government officials from the United States, Latin America, Western and Eastern Europe, Asia, and Africa. Issues included: What potential exists for the control of technology and its direction toward the attainment of social goals? Can "appropriate technology" in its varied definitions serve as a guide to the technological choices that must be made in the industrialized and developing nations? Is there a possibility for an international convergence of appropriate technologies? Edited proceedings of the conference will be published in book form during the spring of 1979.

A series of workshops and a final summary conference on ethics and values in agricultural research were held during the spring and summer of 1978 by a group at the Social Science Division of the University of California, Santa Cruz. These meetings brought together agricultural researchers, consumers, labor union of-



International experts. Scientists and policymakers meet in June of 1978 to explore issues associated with the concepts of "appropriate technologies."

ficials, harvest workers, growers, and State agricultural agency and legislative personnel to explore varying value assumptions about agricultural research and to identify the most important ethical issues that are implicit and explicit in setting priorities for that research. The results of the project will be published as a monograph.

A group at Purdue University completed a 2-year, in-depth study of the case of the three engineers who were discharged by the Bay Area Rapid Transit (BART) system in June 1972, after they had taken their concerns about the safety of the system to the public through the mass media. During the course of their research, the Purdue group assembled and studied a large number of documents and interviewed the engineers, their colleagues, the BART Board of Directors and management, and members of the California Society of Professional Engineers in an effort to assess various perspectives on the ethical problems associated with the case. The results, being published as a monograph, will be an

important contribution to the debate on the increasingly compelling issue of dissent within technology-based organizations whose activities have direct bearing on the public interest.

A group at the Institute of Society, Ethics, and the Life Sciences in Hastings-on-Hudson, New York, has completed the first year of a 2-year study of ethical problems associated with scientific research on aggression. The study is focusing on the details of three cases in which research projects dealing with aggressive behavior were aborted due to external social and political pressures. These case studies are providing the basis for a broader analysis of the ethical issues associated with research in areas on the frontiers of science, where there may be major differences of professional and public opinion about the legitimacy and morality of conducting and applying research.

A group at Montefiore Hospital and Medical Center in New York City is engaged in a project on ethical issues in the delivery of health care within de-

tention and correctional institutions. Its objectives are twofold: (1) to provide health care professionals, students, and trainees with the skills required to identify, articulate, and analyze the relevant ethical and legal issues; and (2) to develop teaching methodologies and materials that can be used at other institutions. The project is being carried out at the Riker's Island Correctional Complex and is being overseen by an advisory committee of physicians and former inmates at the complex.

A grant from the EVIST program permitted the American Association for the Advancement of Science to complete and publish, in fiscal year 1978, a resource directory of programs and courses at U.S. colleges and universities related to ethics and values in science and technology. The survey revealed that nearly 120 programs and over 900 courses in over 500 institutions are directly concerned with these issues. The directory outlines current academic efforts in the area, thus serving as a useful resource to institutions that are already offering courses and programs on ethics and values in science and technology, as well as to those that are contemplating such activities.

Public Understanding of Science

The objective of the public understanding of science (PUOS) program is to help nonscientists understand the activities and methods of science and the implications and issues raised by new discoveries. PUOS utilizes a variety of media to help the public learn about science-related issues in an informal and recreational milieu.

In the area of broadcasting, for example, the NOVA television program continues to reach a national audience of 4 to 6 million viewers each week with programs that range from nuclear safety to the origin of the universe. But many science-related policy



Young advisers. Children's Television Workshop researcher Hylda Clarke gets the help of a panel of young advisers as preliminary research for a daily TV series about science and technology gets under way. The Workshop's researchers have had the assistance of over 6,000 8- to 12-year olds as they plan the new series that will be shown on PBS in 1980.

issues are of regional rather than national interest, so some kinds of programs are more appropriately oriented to a regional perspective. To explore this approach, the public television series "Synthesis" is being produced by a western regional consortium under the leadership of KPBS-TV, San Diego. Programs this year have covered such topics as the impact of

Alaskan oil shipments and the allocation of western water resources.

Many public understanding problems can be related to a general lack of familiarity with science. To address this long-term problem, NSF has provided major support for a new half-hour daily public television program for 8- to 12-year olds, which will begin broadcasting in the fall of 1979. The

series will treat all aspects of science and will present basic concepts of science as well as the excitement and joy of discovery.

Museums are another important channel of informal science education. In the past year traveling exhibits from the Association of Science and Technology Centers in Washington, D.C. (supported by NSF since its inception), reached an audience of over 30 million people. The association also conducted seven workshops, each attended by about 100 museum professionals, on topics ranging from science interpretation and museum management to exhibits for the handicapped.

In order to increase the impact of its limited resources, the program initiated support for duplicate exhibits. The Columbus, Ohio, Center of Science and Industry, for example, has produced ten copies of their hands-on chemistry exhibit for roughly the same cost as the single original exhibit. Two similar grants have been made to develop duplicate exhibits about computers and coral reef ecology. The latter, to be developed by the

Smithsonian Institution, will be placed in several large museums of natural history and will ultimately be seen by about 10 million people each year. It will be the first time that a living coral reef, complete with the hundreds of associated plants and animals that make it self-supporting, will be seen in such museums.

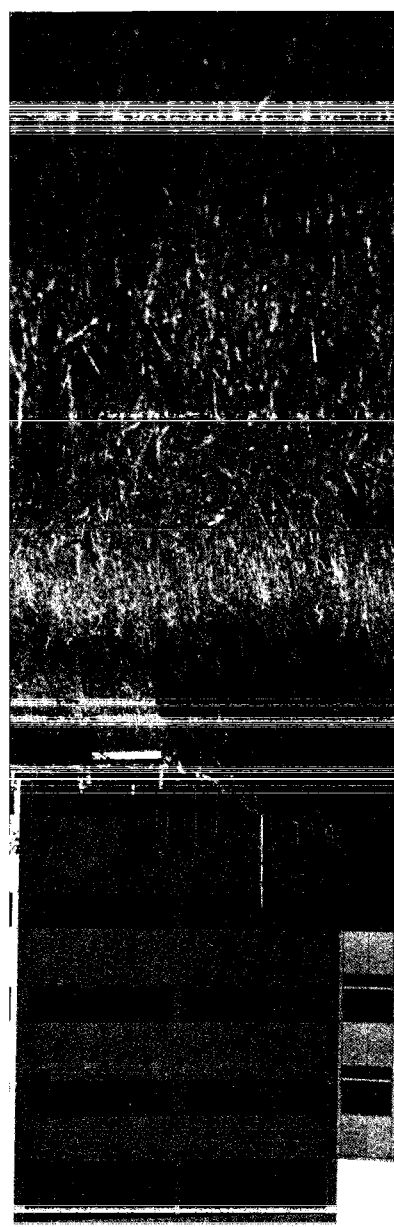
Few journalists have a scientific background and few scientists have familiarity with the needs of working journalists. To bridge this gap, the American Association for the Advancement of Science conducts a mass media intern program, which annually offers 18 young scientists summer experience as science journalists. These exceptional interns have generated an impressive variety of materials, ranging from short articles and radio and TV scripts to wire service articles.

One way to demonstrate the relevance of science and technology is through materials that focus on the interests of smaller and more sharply defined publics. Clark College in Atlanta, Georgia, for example, has recently developed an experimental

science column in which articles, written by Black journalists in cooperation with the Fernbank Science Center in Atlanta, are addressed to the interests of Black readers. The column is already being carried by 50 Black newspapers throughout the country.

Lecture series supported by NSF are chosen largely for their secondary impact through radio, television, and newspapers. For example, although West Coast lecture series on topics like energy and ocean resources have been attended by audiences of up to 55,000, their main impact has been through newspaper and broadcast coverage. Newspapers in six West Coast cities have run comprehensive summaries of the lectures opposite the editorial page, and studies have shown that readership far exceeds that of the editorials.

NSF has also provided briefings for journalists about developments in mental health (through the American Psychiatric Association) and research frontiers (through the Council for the Advancement of Science Writing), and has supported workshops to improve the skills of university science writers.



Applied Science and Research Applications

5

The Applied Science and Research Applications (ASRA) program identifies and supports research and related activities that can contribute to the understanding and resolution of significant problems of national importance. ASRA's specific goals are to:

- Foster growth of fundamental scientific understanding and capability in areas most relevant to emerging or existing national problems.
- Focus U.S. scientific and technological capabilities on selected problems of national significance where NSF can make a unique contribution.
- Encourage the application of fundamental scientific and engineering capabilities to significant problems in the public and private sector, and shorten the time between scientific discoveries and the application of these discoveries for societal use.
- Increase the use of science and technology in the public and private sectors.

To implement these goals, ASRA focuses on the following areas:

Problem analysis—analysis of the role that science can play in contributing a base of information and technology relevant to addressing important societal problems. Such analyses have

included appropriate technology, arid and semiarid lands research, design of the built environment, economic growth under environmental and resource constraints, and science and technology for the physically handicapped.

Integrated basic research—support for basic research that has high relevance to major national problems and provision of a formal link between the NSF programs supporting basic research and those of ASRA. Areas for emphasis include advanced measurement investigations, deep mineral resources, biogeochemical cycles of selected elements (such as carbon and nitrogen),

and population redistribution.

Applied research—support for projects initiated by the scientific research community to improve understanding of various social, economic, policy, and technical problems and to increase the rate of innovation stemming from discoveries in science and engineering.

Intergovernmental science and public technology—integration of science and technology resources into the activities of State and local governments, and test and evaluation of incentives that the Federal Government may use to increase R&D investment in the private sector and to stimulate the acceleration of innovative technology

Table 9
Applied Science and Research Applications*
Fiscal Years 1977 and 1978

(Dollars in Millions)

	Fiscal Year 1977		Fiscal Year 1978	
	Number of Awards	Amount	Number of Awards	Amount
Problem-Focused Research				
Applications	194	\$22.14	229	\$27.02
Applied Research	270	29.59	136	18.06
Intergovernmental Science and Public Technology	94	6.15	127	7.96
Integrated Basic Research	28**	4.47**	9	0.62
Problem Analysis	—	—	17	1.45
Total	586	\$62.35	518	\$55.11

*Research Applied to National Needs (RANN) program was reorganized into the Applied Science and Research Applications (ASRA) program on February 6, 1978.

**Reflects amounts obligated under the Weather Modification and Telecommunications programs of RANN that are applicable to the Integrated Basic Research program.

SOURCE: Fiscal Year 1980 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

into those areas of the private sector where the national interest is served best.

Problem-focused research applications—support of research to clarify and/or resolve critical societal problems by the

application of science and technology. Emphasis is on earthquake hazards mitigation, chemical threats to man and the environment, alternative biological sources of materials, and community water management.

needed new developments and also worked with handicapped scientists for the special insights they could bring to guide ASRA as to how to direct applied physical and social science research to the problem.

The final program goals reflect the need for ASRA to draw developments in basic research through early tests in application and the proof-of-concept phase, develop low-cost technology needed by the handicapped, study the behavioral issues involved in the interaction between the handicapped and the nonhandicapped population, and understand how public policy and economic incentives affect the development of technology for the handicapped and the integration of the handicapped into the mainstream of society. When the program planning phase is complete, the program will be transferred to ASRA's problem-focused research applications program in fiscal year 1979.

Problem Analysis

The problem analysis program studies how science can contribute to a base of information and technology relevant to important societal problems. The program identifies emerging societal problems in which science and technology may have a significant impact, analyzes the appropriate role for the science community and the Federal Government, and determines research priorities. The NSF program staff works closely with the research community and interested publics to examine the nature of the problem area, the needs for scientific input, the role of the Federal Government, and the need for an ASRA program to support research in the area. The program then develops recommendations for those areas where it is determined that ASRA could foster the growth of an applied scientific capability and help to focus it on the problem area.

During fiscal year 1978 the program analyzed research needs in appropriate technology, arid and semiarid lands research, science applied to the design of the built environment, economic growth under environmental and resource constraints, food and nutrition, science and technology for the physically handicapped, and science and technology to aid local governments.

The process used to identify research needed to focus science and technology on the problems of the physically handicapped is an example of the kinds of activities that must be performed to develop a new program area. It was first determined that NSF's comparative advantage was its ability to draw upon talents from a wide range

of disciplines in the research community and then focus on the problems of the handicapped. To determine just how to bring this about, the program surveyed ongoing activities in NSF's basic research areas to identify knowledge that could be directed to the problems of the handicapped.

Building on that base and on a sound knowledge of other ongoing Federal programs, the problem analysis program worked with the research community to gather suggestions for

Integrated Basic Research

This program, which formally links NSF's basic and applied research programs, provides additional support in selected research problem areas where increased fundamental understanding is likely to contribute to the long-term solution of the problems. The support is channeled through the basic research programs. The objective of the program is to increase the stock of fundamental knowledge applicable to existing or emerging major problems.

During the past year the program staff identified 24 topic areas where basic research can be brought to bear on important or emerging problem areas. Additional advice and guidance was obtained through a broad consultative process with scientists at universities and in industry. Additional topic areas to be selected for consideration of support will be developed during fiscal year 1979 by multidisciplinary

workshops, conferences, and seminars as a normal part of NSF's support of basic research.

As of the end of fiscal year 1978, an advisory subcommittee had recommended eight priority topic candidates for support in 1979. Of those, the following areas will be emphasized.

Advanced measurement investigations: to develop new measurement and observational concepts and to improve existing techniques as a way to help science move in new research directions.

Deep mineral resources: to lay the scientific foundation for new technology to find deep ore bodies and recover mineral resources.

Biogeochemical cycles of carbon, nitrogen, and sulfur: to understand the geochemical cycles of important elements, the perturbations of these cycles, and the resultant biological, ecological, atmospheric, and social impacts.

Population redistribution: to examine the unanticipated population redistribution patterns in the 1970's that have complicated planning at the regional

and community levels and to provide improved submodels and improve prediction capability for population redistribution patterns.

Applied Research

The applied research program provides a mechanism to support a broad range of projects initiated by the scientific research community; as such, it is a complement to the more tightly structured problem-focused research applications program. Responding to projects of long-term as well as more immediate utility, the program supports innovative research to improve understanding of various social, economic, policy, and technical problems and to increase the rate of innovation stemming from discoveries in basic science.

To accommodate the broad range of proposals expected and to ensure their adequate review, the program is divided into two broad sections. Social and behavioral sciences includes public policy and regulation, public service delivery, industrial organization and markets, and individual and group processes. Physical, mathematical, and biological sciences and engineering includes physical, mathematical, and geophysical and environmental applications. This administrative structure broadly reflects the basic research programs of the Foundation and is designed to extend basic scientific advances into useful application.

In addition to the broad areas of support there are several "coherent area" programs organized around a generic topic. These are areas in which there is evidence of capability and interest in the research community, a unique role for NSF in organizing or advancing a field of knowledge, and a receptive "user" community. Coherent areas, which provide stable support for a research area for a period of time, are

reviewed periodically and replaced as the opportunity and need arise. Three initial coherent area programs were selected after a review of 16 candidate programs that had been part of the Foundation's Research Applied to National Needs program, which was the predecessor of the current ASRA program. Those retained are: regulation, growth, income, and employment; telecommunications; and production research and technology. The others were phased out as formal programs. About one-third of the programs' resources are expected to be devoted to support in these areas. Examples of recent research results are presented on the following pages.

Edward Denison of the Brookings Institution in Washington, D.C., examined the effects on national productivity of three factors: (1) new legal requirements to protect the physical environment against pollution, (2) new regulations aimed at protecting the safety and health of workers, and (3) social conditions such as increases in the crime rate. He concluded that these factors accounted for a reduction in the annual growth rate (over what it would have been in the absence of those factors) by 0.5 percentage points from 1974 to 1975.

Also at the Brookings Institution, Joseph Pechman completed research on the distribution of the tax burden at each level of government among households of different composition and among households ranked by size of income. The research provided detailed tabulations of the incidence of the entire tax system by income class; for subgroups of the population such

as elderly, homeowners, and renters; and for urban and rural groups. The research also provides data on individual taxes or combinations of taxes. The study contains an analysis of tax reform at both the corporate and individual level, as well as an estimate of the effects of inflation on personal tax liability.

Researchers at Data Resources, Inc., in Massachusetts, at Northwestern University, and at the University of Wisconsin have completed a study of the impact of regulation on productivity in the railroad industry. The study, which compared U.S. railroads with the less regulated Canadian railroads, concludes that extensive U.S. regulation results in smaller productivity increases than might be forthcoming with less regulation.

Two Harbridge House research teams in California and Massachusetts are contributing to a better understanding of the costs and benefits of regulation. They have developed a complete mathematical, computerized system of models to analyze regulatory impacts on metallic mining industries and have assembled the most complete and accurate data base available on the copper industry. They are using this data base, with the models, to analyze both monetary and nonmonetary benefits and costs of a number of regulations affecting copper production. The White House Non-Fuels Policy Coordinating Committee is using the Harbridge House methods to structure its overview. The Environmental Protection Agency is using the computer models for an online capability for all future economic assessments of environmental regulatory impacts on the copper industry. The American Mining Congress is using the models in their own case study of proposed EPA arsenic regulations. The U.S. Bureau of Mines is using the model specifications to link into their Mineral Accessibility System, which monitors regulatory impacts on mining.

The combined use of telecommunications and computing technology is

frequently posed as a way to reduce travel and enhance productivity in white collar occupations. Results from a year-long experiment conducted in actual work settings suggest that computer conferencing increases communications among geographically distributed workers, increases flexibility in acceptable place of work for cooperative research endeavors, and promotes greater productivity than alternative communication modes such as mail or telephone. However, the amount of travel needed to accomplish various tasks was not significantly reduced, and no substantial changes in when the activity was performed, such as after normal office hours, were found. There was little to suggest that organization decentralization results from the use of the new medium. Overall, the study conducted by the Institute for the Future in Menlo Park, Calif., concluded that computer conferencing could become a competitor to mail and telephone services.

Research findings from several experiments dealing with the use of telecommunications for increasing the productivity of public sector services were major contributions to a NATO Symposium on the Evaluation and Planning of Interpersonal Telecommunication Systems. The symposium brought together policymakers and scientists from nine countries to review national and international telecommunications policy, applied research, and industrial development.

A large fraction of manufacturing today involves production of relatively small batches. Significant productivity gains, through automation, appear possible in this small batch production, but the familiar assembly line techniques are not applicable. Instead, systems involving programmable devices, such as numerically controlled machine tools and industrial robots, are needed. NSF is supporting a number of projects in this area, including a study at Purdue University of efficient and advanced methods of control for in-

dustrial robots. As a result of research there, the amount of computing time required to determine the position of the robot hand has recently been reduced by a factor of about 100. An optimization method has been formulated to determine the path of motion of the manipulators, and a scheme has been worked out to control the relation of manipulation joints efficiently. At the University of Rhode Island researchers have recently placed an experimental robot system into operation. This system uses a TV camera to aid in picking up an arbitrarily positioned workpiece from a bin, computing the position of the workpiece, and placing it in a predetermined place at a selected site. Collisions are avoided, and the workpiece can be regripped in the course of the movement. These results will be useful in improving industrial efficiency in the United States.

Research on the reduction of porpoise mortality during fishing for tuna is continuing. In fiscal year 1978 researchers from San Diego State University and the Hubbs-Sea World Research Institute began conducting at-sea experiments using the purse seiner M/V *Queen Mary*, which has been made available by the tuna industry for research on the tuna-porpoise mortality problem. The results of these experiments will be used in developing the conceptual design of an artificial aggregation system for tuna to eliminate the need for purse seining.

E. S. Savas at Columbia University, in conjunction with Public Technology, Inc., and the International City Management Association, produced a document, *Evaluating Residential Refuse Collection Costs: A Workbook for Local Government*, which may be used by urban policymakers to assess the effectiveness and efficiency of their solid waste collection operations.

Robert Haskell of the Westinghouse National Issues Center, in conjunction with the Municipal Finance Officers Association and the International Personnel Management Associ-

ation, wrote a report (*Payroll/Personnel Management System*) that identified the requirements of small- to medium-sized jurisdictions in the payroll/personnel management area and developed computerized systems to be used in fulfilling these requirements.

The Marshall E. Dimock Award of the American Society for Public Administration was recently presented to James N. Danziger, principal investigator on the NSF-supported urban information system project at the University of California, Irvine, for his article "Computers, Local Government and Litany to EDP." The article was selected as the most meritorious paper published in the *Public Administration Review* during 1977.

The Government Finance Research Center of the Municipal Finance Officers Association has produced seven manuals on financial management techniques for smaller cities. These were selected for display at the 1978 National Demonstration Conference sponsored by the American Society for Public Administration and the Civil Service Commission. Projects displayed were cited for addressing traditional problems in new ways and for their promise to be useful across the country. The seven manuals developed under the NSF award are on financial policy, fiscal indicators, operating budget, capital budget, accounting, debt management, and treasury management.

The growing demand for corrosion-resistant, longer lasting products has prompted increased use of zinc-based protective coatings in maritime construction, highway structures and bridges, nuclear powerplants, and automotive undercoats. In 1976 approximately 65,000 short tons of zinc dust were used in the United States for primer applications. However, currently used air atomization spray techniques result in zinc losses of over 50 percent. The wasted zinc collected from the spray booths is disposed as landfill. The obvious environmental hazards of disposal, coupled with the

fact that half of the U.S. zinc supply is imported, prompted engineers at the University of Louisville, Kentucky, to create an efficient application technique and to find ways to recycle and reuse the waste zinc from the conventional spray process. They built and tested electrostatic spray equipment, which laboratory experiments indicated reduced the wastage by approximately 40 percent. A full-scale, four-spray, automatic, electrostatic spray system is now under design and construction with industrial cooperation. Waste zinc from primer applications was recovered as pure zinc by drying, screening, and solvent extraction. Laboratory tests indicate that zinc sulfate needed for the fertilizer industry can be produced economically from the waste zinc primer.

A research project investigating investment behavior in the minerals industry—including nickel, zinc, phosphate, aluminum, copper, iron ore, and sulfur—was recently completed at Pennsylvania State University. The findings, as predicted by theory, are that the demand situation plays a major role in investment decisions. For those commodities like aluminum and iron ore, where demand estimation does not involve great uncertainty, a smoother investment pattern is exhibited relative to actual demand. For those commodities where demand estimation is difficult, such as nickel, copper, and zinc, there were more pronounced periods of undercapacity and supply shortfalls with respect to effective demand. Somewhat surprising was the relatively minor and indirect role played by current and projected prices of the commodities in question. Much more significant than prices was the market structure of the industries and changes in that structure over time. Most important of all was the major and direct impact of Government policies, both of the United States and of other countries. For example, the zinc stockpile decisions in face of surplus capacity in the 1950's led to substantial undercapacity in the

1970's. Another example is the Government's deliberate policy of fostering entry into the nickel industry through stockpile purchases, which has led to a very difficult industry structure and somewhat less efficient investment patterns.

One of the problems in determining the nutritional value of proteins in foods is the time and expense of present assay methods. The standard test now requires feeding rats for 30 days

to determine their weight increase. However, experiments at the Haskins Laboratory in New Haven, Conn., indicate that the protozoan tetrahymena may be useful in evaluating proteins in foods that have relative protein content at least one-quarter that of the milk protein casein. That would include most foods of interest to industry. Test with tetrahymena would be much faster and less expensive than the conventional rat tests.

Problem-Focused Research Applications

The problem-focused research applications (PFRA) program applies new scientific and technological discoveries to selected, critical national problems. Research supported by the program is intended to help accelerate resolution of problems rather than to increase knowledge in a particular area. PFRA programs require a multidisciplinary approach to problem solving and encourage cooperative research efforts involving industry, universities, and government agencies. Projects range from the development of basic new information to proof-of-concept experiments. The array of program areas will change over time as ongoing programs are either transferred to Federal mission agencies or phased out as their objectives are achieved. There were four programs in PFRA in fiscal year 1978: earthquake hazards mitigation; chemical threats to man and the environment; alternative biological sources of materials; and community water management.

Earthquake Hazards Mitigation

The objectives of the earthquake hazards mitigation program are to minimize loss of life and to reduce

property damage due to earthquakes. The three major research areas are siting, design, and policy.

Siting focuses on the relationship between soil and geologic conditions at a given site; the potential earthquake hazard of the region; and the architectural, land use, and engineering practices and policies necessary to make buildings at that site earthquake resistant.

Design investigates the elastic and inelastic behavior of building material; the effects of design, construction, and type of building materials used on the behavior of structures during seismic and wind excitation; ways to minimize the risk to older buildings not built to meet earthquake code standards; and the behavior of nonengineered structures and secondary components of buildings.

Policy deals with social, economic, legal, institutional, and other factors that facilitate or hinder the adoption of social and technological solutions, including prediction and warning, to earthquake hazards.

The results of this research are applicable worldwide, and cooperative research activities already exist with the Soviet Union, Japan, the Republic of China, and India.

The architectural firm of McCue,



Seismic design. This architectural award-winning IBM laboratory in San Jose, California, follows earthquake-resistant design criteria developed in earlier research supported by NSF. (Photo by Marvin Wax)

Boone, and Tomsick received an American Institute of Architects 1978 Honor Award for their design of the IBM Santa Teresa Laboratory in San Jose, Calif. This building complex reflects the direct application of NSF-supported research findings on the relationship of nonstructural design elements—such as the primary enclosure system, ceiling systems, partitions, and window glass—to the performance of the building's primary structure during earthquakes. The seismic design features of this building complex show that seismic and energy design factors can be incorporated into building design while still permitting architects aesthetic flexibility.

In the past year Mete Sozen and William Schnobrich of the University of Illinois, Urbana, have developed a new conceptual model to determine the energy dissipation and distribution of forces in buildings consisting of combinations of structural shear walls and frameworks of reinforced concrete. This research project was based on the design, construction, and

earthquake-simulation testing of small-scale, slender, multistory buildings with differing proportionate strengths and stiffnesses provided by the frame and wall components. The results of this research will be of great value as the basis for improved design methods.

Chemical Threats to Man and the Environment

Research in this area is aimed at determining chemical pathways and transformations in the environment and in organisms, identifying and measuring environmental contaminants and their effects on living forms critical to the functioning of ecosystems, and developing ways to predict the toxicological effects of chemicals on humans based on animal test and laboratory data.

Glen Gordon of the University of Maryland has developed a better means to identify the sources of particulate airborne contaminants than had previously been available. Gordon's

project has defined the characteristic contributions of important manmade "source types," including powerplants, roadway traffic, waste incinerators, and industrial sources. Each of these source types produces emissions with characteristic chemical compositions for certain-sized particles. This knowledge enables the correlation of airborne contaminants in areas of human exposure to their probable origins.

Gordon's project examined the occurrence of about 30 chemical elements in airborne particulates and described how these elements are distributed into finer, respirable particles. Aircraft sampling of copper smelter plumes in the Southwest showed that, in addition to copper, the plumes from five smelters contained easily detectable levels of zinc, cadmium, lead, arsenic, antimony, bismuth, bromine, vanadium, molybdenum, tungsten, and indium. Chemical analysis of the plume samples has proved that it is possible to identify individual smelters as the sources of specific contaminants. Such information will be of



Domestic rubber. Scientists at Los Angeles County Arboretum are collecting, hybridizing, and growing different strains of the desert shrub guayule, which contains natural rubber, in an attempt to provide a commercial alternative to imported rubber. Plants growing in this desert-like field are irrigated inexpensively with reclaimed water from a nearby sewage treatment plant.

use to Federal and State officials in enforcing environmental protection regulations concerning airborne contaminants.

In a well intentioned effort to prevent burn injuries, the Federal Government implemented strict regulations for many natural and synthetic fabrics with regard to fire retardancy. As is often the case with new chemicals, some flame retardants were in wide use before they had been tested to determine whether they posed any health risk to those exposed to them. One chemical widely used to fireproof children's sleep clothes, TRIS, proved to be highly carcinogenic; as a result, its use has since been banned by the Food and Drug Administration. A project currently being supported by the chemical threats program under the direction of Benjamin Van Duuren of New York University has shown that TRIS, when applied to the skin, causes malignant tumors of internal organs, an unusual and important finding. Van Duuren will further investigate whether TRIS and other halogenated

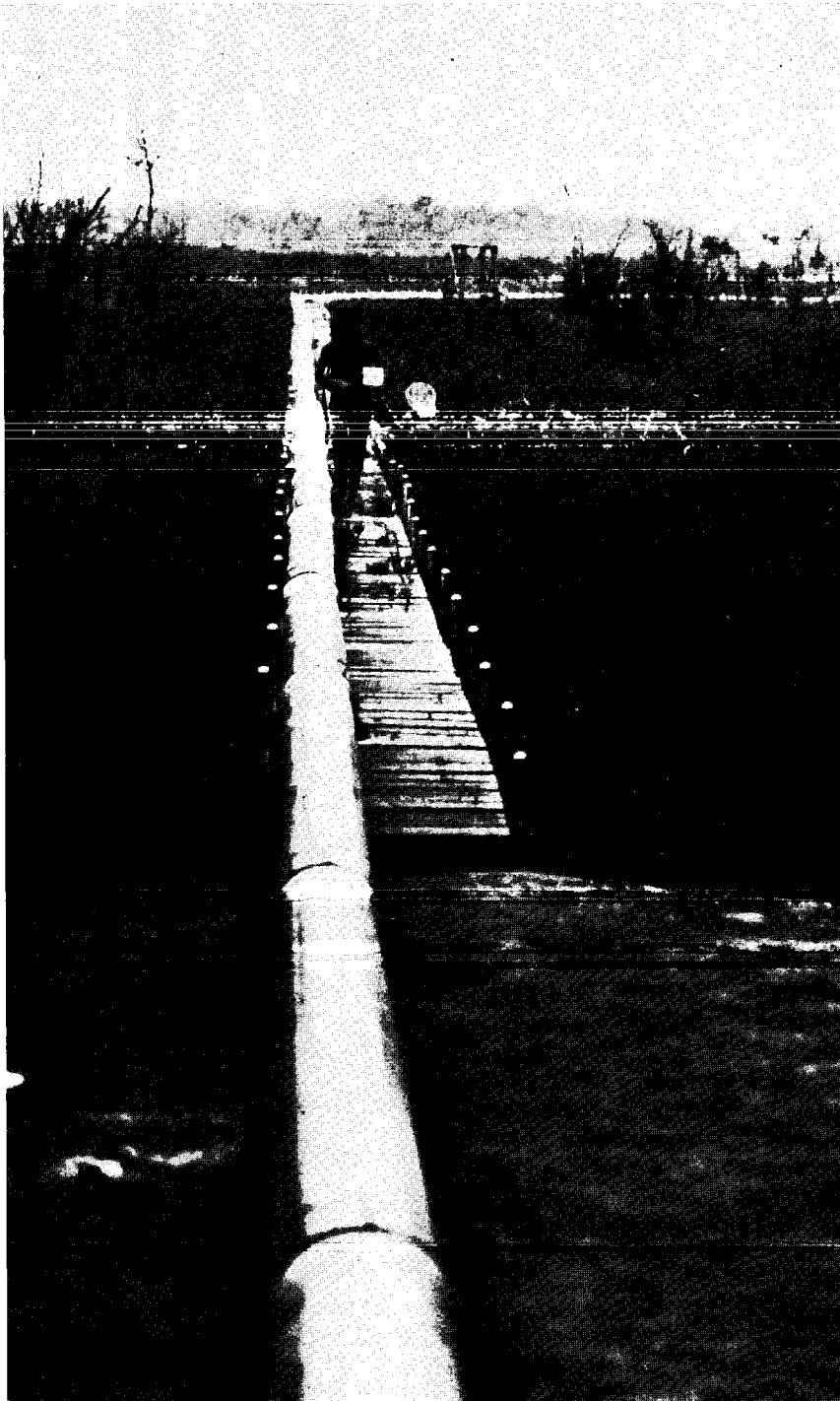
hydrocarbons are direct-acting carcinogens or whether they are metabolized to carcinogenic intermediates by the organism.

Alternative Biological Sources of Materials

This program supports research to alleviate the Nation's dependence on imported, scarce raw materials by developing domestic biological substitutes. The program focused on three areas in 1978. Biological conversion of lignocellulosic materials dealt with the replacement of petroleum with chemical feedstock derived from the conversion of agricultural and forest residues by the use of enzymes or microbial systems. Biological nitrogen fixation studied processes to enhance natural bacterial nitrogen fixation to reduce the need for chemically synthesized fertilizers, which require natural gas for their manufacture. Investigations on guayule and jojoba sought to develop domestic sources for natu-

ral rubber and liquid wax to replace *Hevea* rubber from Southwest Asia and the industrial oil from the sperm whale.

The nitrogen required by plants for growth either can come from industrial fertilizers or can be naturally derived from atmospheric nitrogen by certain bacteria in the soil. Winston Brill at the University of Wisconsin, Madison, is trying to enhance biological nitrogen fixation by coating legume seeds with specific protein that binds nitrogen-fixing bacteria to the roots of the plant; he is also developing "supermutant" strains of these bacteria. Results to date have been encouraging; coating of the seed with protein does attract more bacteria, and "supermutant" bacteria can produce up to twice as many root nodules per plant. Soybean plants grown in soil with "supermutant" bacteria have shown a dry weight increase of 20 percent. If successful, this research will result in a more economical and effective way to use natural processes to produce plant protein.



Wastewater management. Researchers from the University of Michigan are cooperating with the Houghton Lake community in studying effects of applying treated (secondary-stage) wastewater to a peat wetland. This NSF-supported, full-scale experiment now under way results from earlier basic and applied studies of waste-assimilative capacities of wetland ecosystems.

Community Water Management

Agricultural, industrial, and community demands for water in the United States have reached a point where quantitative and qualitative limitations are becoming increasingly apparent. Re-use of water, whether direct or indirect, is now the rule rather than the exception. This program supports the scientific investigation of means to meet community needs for management of water and waste water, including existing social, institutional, and economic barriers to the introduction of innovative concepts. Research results are targeted to engineers who provide consulting and design services to communities, and to local, State, and Federal regulatory agencies.

Since 1972 NSF has supported a sequence of research projects under the direction of Robert and John Kadlec of the University of Michigan. Basic research on wetland ecosystems led to studies of the effects of the application of treated waste water on wetland ecosystems; next, to applied studies and systems modeling for treatment plant facilities; and then to verification of the efficacy of applying secondarily treated waste water for recovery of water and nutrient values by the peat wetlands of the region. The success of the research led, in the spring of 1978, to completion by the State of Michigan of a full-scale, proof-of-concept, advanced waste water treatment plant for the Houghton Lake Sewer Authority. The project is an excellent example of complementary, well coordinated efforts on the part of three Federal agencies (National Science Foundation, Environmental Protection Agency, and the Fish and Wildlife Service) and State and local governments cooperating with the private profit and nonprofit sectors (Williams and Works, Inc., and the Rockefeller Foundation). In addition to providing safe management for the waste water of the Houghton Lake Sewer Authority, the new treatment

plant will save an estimated \$750,000 over land application, the next most cost-effective alternative, over the next 20 years.

Intergovernmental Science and Public Technology

Intergovernmental Programs

Intergovernmental programs assist State and local governments to integrate scientific and technological resources into their policy formulation, management support, and program operation activities. The programs also sponsor projects that help the science and technology community respond to the needs of State and local governments. Special attention is given to developing and demonstrating new mechanisms and processes to improve communications between resource suppliers and State and local government users.

In fiscal year 1978, awards were made in four areas: local government, State government executive branch, State government legislative branch, and science and technology resources.

The major focus of the local government programs was support for national and regional innovative networks. There are three national networks: the Urban Consortium for Technology Initiatives, composed of the 28 American cities and 8 large urban counties with more than 500,000 population; the Urban Technology System, composed of 26 cities and counties in the 50,000 to 500,000 population range; and the Community Technology Initiatives Program, composed of 32 cities and counties with populations of under 50,000. These national networks bring together local governments dedicated to finding and using new ways to improve productivity and the quality of services. The networks develop research and development agendas, involve member jurisdictions in research, and provide a

system to demonstrate and replicate research findings. These national networks, along with the State and regional innovation networks, provided the primary input into the R&D needs assessment conducted by the President's Office of Science and Technology Policy in response to the request of its Intergovernmental Science, Engineering, and Technology Advisory Panel.

Continued support was provided to State and regional innovation groups in California, New England, Texas, Ohio, Colorado, Georgia, Tennessee, and Oklahoma, and resources were provided to assist emerging networks in the Delmarva Peninsula (Delaware, Maryland, Virginia) and the Pacific Northwest. Funds to support the networks were provided through various projects with the International City Management Association, National League of Cities, National Association of Counties, and the United States Conference of Mayors.

The State government executive and legislative branch programs devoted considerable effort to ensure successful completion of the planning phase of the State Science, Engineering, and Technology (SSET) program. In this phase, awards were made to the executive branches of 49 States and to the legislative branches of 42 States for analysis of ways to increase their capability to use science, engineering, and technology in policy management. A third-party assessment of the program, conducted by SRI International, concluded that there should be continued Federal investment in this effort through an implementation phase.

In addition to the special thrust represented by the SSET program, other

significant developments occurred in both the executive and legislative branch programs.

The executive branch program continued to emphasize awards to the national organizations representing State government, such as the National Governors' Association, the Council of State Governments, and the Council of State Planning Agencies, to identify policy areas in which more knowledge is needed, transfer successful innovative approaches among the States, and provide expertise to deal with policy issues in such areas as energy, environment, and growth. An emerging area of importance was reflected in a series of awards to regional groupings of States to increase their capacity to access scientific and technological support. Awardees in this category included the Western Governors' Policy Office, the Coalition of Northeastern Governors, the Southern Growth Policies Board, and the Midwestern Governors' Conference.

The legislative program supported several State legislatures to demonstrate ways to improve their scientific and technological information. Among the recipients of these awards were the Pennsylvania Legislative Office of Research Liaison, which links the Assembly to six State-supported universities; the scientific staff of the Minnesota Legislature; and the Science Resources Office of the Legislature in Massachusetts. An award was also made to the National Conference of State Legislatures to develop a comprehensive information system among the Legislatures and to connect the Legislatures with selected Federal agencies.

Support for Federal Laboratory Consortium activities was expanded and the consortium's membership increased from 150 to 183 laboratories. An award to the China Lake Naval Weapons Center provided funds for the consortium secretariat. Consortium laboratories increased their assignment of technical personnel to State and local governments under the

Intergovernmental Personnel Act, including the assignment of seven "circuit-riding" technology agents and a technology coordinator to the community technology initiatives program.

NSF also increased its efforts to develop a comprehensive evaluation program. Two significant activities were the use of a specially selected panel of research managers and State and local executives and legislators to help develop the program, and the award of a contract for the collection of baseline data on the activities of the Urban Technology System and preparation of a detailed evaluation plan for that project.

Industrial Program

The industrial program is a major factor among Federal R&D pro-

grams concerned with the role of science and technology in U.S. economic development. It is the only program conducting field experiments designed to extend knowledge in this area. The health of science in America depends upon improved understanding of the mechanisms by which scientific discovery is brought to productive use.

The industrial program tests and evaluates selective incentive strategies that the Federal Government might use to increase R&D investment in the private sector of the economy and to stimulate the introduction of innovative technology into commercial use, especially where new products, processes, or services are needed in the national interest.

The program conducts four types of experiments, based on the following goals: to capture the high innovative

capacity of small business through the award of specific research grants; to shorten the time lag between scientific discovery and market commercialization through cooperative research projects; to assist in the development of innovative and entrepreneurial skills through institutionally based innovation centers; and to provide a university research resource to segments of industry by means of university-industry research centers.

The first two kinds of experiments are characterized by technological research that can be used by a company or industry without any attempt to build a lasting institution, while the latter two depend upon the creation of an institution. In practically all of the experiments university educational and research personnel and faculties have been mobilized to stimulate and assist private sector R&D activities



Technological innovation. These two new biomedical products were developed at the University of Utah's innovation center. (Left) This portable kidney dialysis unit is currently being evaluated for its market potential. (Right) The Dermatron, a simple iontophoresis device that uses a low-level electric current to diffuse local anesthetic painlessly into surface tissue, is already being marketed to hospitals and doctors.

and, as such, have aided in the introduction of new products by working with large and small firms and through new firm initiation.

The experimental results have shown a national impact on (1) innovation and entrepreneurial education, (2) new product evaluation and development techniques, (3) new business initiation and assistance methodology, and (4) economic development. Results have ranged the spectrum from new biomedical products to conservation of resources; industries aided vary from traditional, with low technology bases, to those using sophisticated technology, such as digital taxi meters, security and heating and cooling control systems, new insulation materials, and a substitute for oak flooring.

The industrial program has had a successful 5-year history of conducting experiments on alternative modes of promoting a university/industry interface and is developing a body of knowledge on new institutional arrangements for applying university-based resources to industry needs.

Communications Programs

The communications programs disseminated over 53,000 ASRA research reports to interested user groups through a variety of channels: presentation of specialized ASRA document displays and lists at professional meetings and conventions; cooperative activities with ASRA program managers among industrial, small business, and appropriate technology communities; the publication *Recent Research Reports*, which has achieved a distribution of over 3,000 copies per issue; and sales by the National Technical Information Service of the Department of Commerce.

Experimental Program to Stimulate Competitive Research

In fiscal year 1978 the National Science Board established the experimental program to stimulate competitive research. The program is intended

to improve the quality of science and increase the ability of scientists in eligible States to compete successfully for Federal research funds. It reflects the Board's perception that significant national as well as local benefits are derived from each State's participation in the national science enterprise. Through the program, NSF assumes responsibility for assisting institutions in States falling below specified minimum criteria to improve their competitive capability in science. At the same time, the States involved accept primary responsibility for their improvement.

The program, to be conducted in fiscal year 1979, consists of two phases. In the first, an ad hoc committee from each of seven eligible States will analyze the status of science and technology in its State and develop a plan to improve the ability of scientists in that State to compete more successfully for Federal research funds. The plans that result from that phase will compete against one another for second-phase implementation awards.



Scientific, Technological, and International Affairs



The Foundation's programs in Scientific, Technological, and International Affairs (STIA) bring together diverse information on science and technology to identify research needs and science and technology policy issues stemming from practical problems and developing needs. The data and analyses that derive from these activities serve as input for domestic and international science and technology decisionmaking. Such input is valuable to public and private sector policymakers, as well as to managers of research and development, who require accurate information and analysis on national and international issues with scientific and technological components.

Within STIA, the main areas of activities are: (1) international scientific cooperative programs, (2) information science and technology activities, (3) policy research and analysis, and (4) science resources studies. Together, these activities systematically monitor the Nation's scientific and technological enterprise and promote improved science and technology information exchange.

International cooperative scientific activities increase science and technology benefits to the United States through international sharing of research approaches, costs, facilities, and results. During fiscal year 1978 this program supported cooperative relationships between U.S. and foreign scientists and institutions by advanc-

ing U.S. participation in international scientific organizations, joint programs and projects, and individual exchanges in research and related activities. Such scientific activities not only served the needs of U.S. science, but also furthered foreign policy interests of the United States.

Information science and technology activities strengthen fundamental knowledge of the properties of information. This program is the only Federal source of funds for research on ways of improving access to and use of information across fields of science. Foundation programs in this area contribute to the scientific and technologi-

cal knowledge needed for the design of science and technology information processing systems.

Policy research and analysis programs facilitate decisionmaking on issues with significant science and technology content. Appropriately, information and analyses are disseminated to users in both the public and private sector. These activities enhance the Nation's science policy research and analysis capability and its decisionmakers' ability to assess alternative science and technology policy options in relation to social and economic goals.

Science resources studies collect and

Table 10
Scientific, Technological, and International Affairs
Fiscal Years 1976, Transition Quarter
(July 1-Sept. 30, 1976), 1977, and 1978

(Dollars in Millions)

	Fiscal Year 1976		Transition Quarter		Fiscal Year 1977		Fiscal Year 1978	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
International Cooperative								
Scientific Activities	690	\$ 7.53	224	\$3.04	684	\$ 8.49	578	\$ 9.85
Policy Research and								
Analysis	157	6.44	28	1.19	82	3.50	88	5.57
Science Resources Studies ...	47	2.08	13	0.76	54	2.79	48	2.51
Information Science								
and Technology	102	5.89	33	0.76	57	4.54	50	4.97
NSF Planning and								
Evaluation	14	0.47	30	0.40	54	1.34	33	0.88
Total	1,010	\$22.41	328	\$6.15	931	\$20.66	797	\$23.78

SOURCE: Fiscal Years 1978, 1979, and 1980 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

analyze data on U.S. human and financial resources for scientific and technological activities. In fiscal year 1978 NSF issued 40 reports to provide comprehensive overviews of the quantity, quality, and direction of the U.S. scientific and technological enterprise.

NSF programs in Scientific, Technological, and International Affairs also contribute to an improved national scientific and technological infrastructure through liaison with various groups in the private and public sector. These include the research community, industry, the National Science

Board, other Federal agencies, State and local governments, the U.S. Congress, and the Executive Office, including the Office of Science and Technology Policy and the Office of Management and Budget.

Also presented here with the programs of STIA is NSF's planning and evaluation activities. This program responds to the Foundation's need to improve the management of its activities and to review and appraise the accomplishments, impact, and adequacy of NSF programs in relation to overall objectives.

Policy Research and Analysis

Policy Research and Analysis (PRA) programs support external studies and conduct internal staff analyses of science and technology policy issues of interest to NSF, groups within the Executive Office of the President such as the Office of Science and Technology Policy and the Office of Management and Budget, other agencies, and the Congress. These activities are part of NSF's efforts, required under the NSF Act of 1950, to "appraise the impact of research upon industrial development and upon the general welfare" and "to provide a source of information on policy formulation by other agencies of the Federal Government."

Further, as directed in the National Science and Technology Policy Act of 1976, NSF provides assistance to the Office of Science and Technology Policy in the Executive Office of the President. PRA contributes to this NSF effort through assessments of the contribution of science and technology to economic progress and individual welfare, analysis of the roles of the public and private sectors in research and development and technological innovation, and studies to clarify the role of science and technology in meeting national energy, environmental, and

resource goals. PRA is also responsive to Public Law 92-484, which amended the NSF enabling legislation and established a provision for NSF to assist the Office of Technology Assessment and to initiate and support studies of the effects of technology upon society.

Policy research and analysis activities are divided into four areas of study: socioeconomic effects of science and technology; environment, energy, and resources; innovative processes and their management; and technology assessment. Descriptions of their respective fiscal year 1978 activities follow.

The Socioeconomic Effects of Science and Technology

The purpose of this program element is to make available for Federal decisionmaking: (1) improved empirical information on the relationship of science and technology to economic performance and the quality of life; (2) improved information about the effects of Government actions on the relationship; and (3) improved methods for generating such information. Projects included:

- Effects of Government regulatory policies and practices on health technologies, a series of related studies funded under grants to the National Bureau of Economic Research, Inc., University of Rochester, Brookings Institution, and the National Academy of Sciences.
- Effects of international technology transfer on the U.S. economy, a series of studies examining determinants and effects on U.S. technological capability and research and development of private sector international technology transactions. These studies were conducted by the University of Pennsylvania, Harvard University, and Battelle Memorial Institute.
- Staff studies assessing the utility of selected R&D output and input data as indicators of U.S. technological capabilities relative to other industrial nations.
- Preparation of a report on the effect of NSF and Government research funding on the incomes of academic research scientists, prepared for the Committee on Appropriations, U.S. Senate.
- Preparation of the sections on research and development and U.S. economic progress, comparative performance of U.S. technology, status of basic research in industry, and some issues in the support of academic science appearing in the 1978 *Science and Technology: Annual Report to the Congress*.

Environment, Energy, and Resources Studies

This element is concerned with science and technology policy choices that influence future environmental quality, energy supply and cost, and resource utilization and development. It supported studies that assessed the

implications for science and technology policy of certain environmental regulations, energy technology development strategies, and minerals extraction options. In addition, the group provided staff analysis of domestic policy issues in these areas. Projects included:

- *The Impact of Environmental Regulations on Research and Development in the Industrial Chemical Industry*, an investigation by Southeastern Louisiana University of the effects of environmental regulations on 15 major R&D centers in the chemical industry.
- An interagency case study of the municipal waste water treatment facilities construction grants program of the Environmental Protection Agency. Although the study focused on national policy aspects, Boston was the site of the case study, and meetings were held there with local, State, and Federal agencies as well as the general public in order to obtain comments on the draft final reports.
- A summary report of the findings of a series of workshops conducted by the MITRE Corporation to advise NSF on the research and technological developments concerning energy facility siting options and attendant problems faced by the energy utilities industry.
- *Electric Utility Decisionmaking and the Nuclear Option*, which analyzed the factors considered by private utilities in their decision to invest in either a nuclear generating facility or a fossil-fuel facility.
- Two Domestic Policy Reviews. The staff participated in the solar impacts panel of the Domestic Policy Review on Solar Energy and in the Nonfuels Mineral Domestic Policy Review, for which NSF was the lead agency for the task on

"Adequacy of Minerals-Related Research and Development."

Innovation Processes and Their Management

This element, concerned with the processes associated with the development and diffusion of technological innovations in the United States, seeks general principles that explain the creation and utilization of technology. Its goal is to identify points where public policies influence innovation in the public and private sectors of the U.S. economy and in the acquisition and use of technology in developing countries. Projects included:

- *Diffusion of Technology in the Domestic Shoe Industry*. This study by the University of Maine at Orono explored the processes of technological change in a specific industry and examined the potential impact of a variety of Federal actions to stimulate such change. Members of the research team later presented findings to the Department of Commerce and other members of the Administration in a number of briefings and workshops.
- *The Impact of Professional Associations on Innovation Diffusion Among City Governments*. This study was carried out by the University of Wisconsin at Milwaukee in order to suggest possible public policy options for improving the transfer of innovations among city governments via professional associations.
- *An Exploratory Study of the Coordinating Mechanisms Between R&D and Marketing as an Influence on the Innovation Process*. This University of Pittsburgh report considered the effects on a firm's R&D projects of various procedures for coordinating research, development, and marketing. Findings may improve

corporate and Federal policymakers' understanding of organizational coordinating mechanisms and their potential for increasing the flow of technology to the marketplace.

- Analysis of developing country papers, which were submitted in preparation for the 1979 United Nations Conference on Science and Technology for Development. At the request of the U.S. Conference Coordinator, the staff analyzed developing country papers to identify common scientific and technological needs, variations in these needs among groups of developing countries, and appropriate mechanisms for technological assistance. The results will aid the U.S. Delegation in formulating U.S. initiatives for the Conference.

Technology Assessment

This program supports research to provide information on the social, environmental, institutional, and economic impacts of the introduction of major new technologies or of expanding existing ones. The 1978 program focused on research that would provide a better understanding of the subtle, long-range implications of implementing technologies. Support was also provided for research to improve methods for the assessment of the impacts of technology and on ways to enhance use of technology assessment in policymaking.

- Among completed research projects were assessments of mobile communications technologies prepared by Cornell University, transportation of cargoes by very large aircraft conducted by Gellman Research Associates, risk to structures from natural hazards by J. H. Wiggins Co., and controlled environment agriculture done at International Re-

search and Technology Corporation. Each assessment explored how a specific technology might evolve and where issues of public policy could emerge.

- Broad areas where new technologies are likely to develop were also studied. Battelle Columbus Laboratories prepared an agenda for technology assessment that identified important developments in the materials field. Similarly, the Georgia Institute of Technology prepared an agenda for assessments of the technologies employed in making the manmade

environment. In addition, research by Portland State University examined the uses of structural modeling as a method for analysis of technology assessment problems.

- In a collaborative effort with the United Nations Office for Science and Technology, the program provided partial support for a workshop/seminar in Bangalore, India, on technology assessment for development. The workshop's theme involved examining the role of technology assessment as a tool for development planning.

tion's R&D effort has occurred each year since 1975, reflecting, in large part, increased emphasis on finding alternative sources of energy. Total R&D spending is expected to reach \$51.6 billion in 1979, an increase of about \$4.3 billion over the 1978 level. (*National Patterns of R&D Resources: Funds and Personnel in the United States, 1953-1978-79*)

R&D Funding

Federal. The President's fiscal year 1979 Budget, as submitted to Congress, includes R&D obligations totaling \$28 billion, an all-time high in current dollars but somewhat below the 1978 total in constant dollars. The 1979 budget reflects greater austerity in regard to R&D programs than some previous ones, in which overall R&D growth exceeded inflation each year. The criteria cited by the Administration for supporting R&D programs were whether they fulfilled direct Federal needs, general social needs where the private sector had insufficient incentive to invest, or the need to accelerate private R&D efforts because of an overriding national interest. A significant rise was budgeted for defense and space R&D programs, with only a slight rise in the level of funding for the civilian areas such as health, energy, and environment, taken as a whole. This would reverse a 13-year trend in which Federal R&D support shifted steadily toward civilian programs. (*An Analysis of Federal R&D Funding by Function, Fiscal Years 1969-79*)

Industrial. Roughly 70 percent of all U.S. R&D funds are used by the industrial sector, with total industrial R&D expenditures increasing at an average annual rate of 5.5 percent in current dollars since 1968. However, the continuing decrease in industry's real expenditures for basic research since 1968 has been a major source of concern in recent years. A study conducted for the NSF by the Industrial Research Institute Research Corpora-

Science Resources Studies

The science resources studies program's primary function is to develop timely and comprehensive overviews of the Nation's human and financial resource systems for scientific and technological activities. The program includes: (1) development and maintenance of a quantitative information base; (2) analysis of data, concentrating on the illumination of current issues and on the identification of factors responsible for current and prospective supply and utilization patterns; and (3) special studies carried out at the request of Federal policymakers such as the Office of Management and Budget, the Office of Science and Technology Policy, and various Congressional committees.

Program activities are divided into three program elements: scientific and technical personnel, funding of science and technology, and modeling and science and technology indicators. A shift of the program toward greater analytical activity has recently been initiated to improve the utilization of large and complex data bases that have been established over the years.

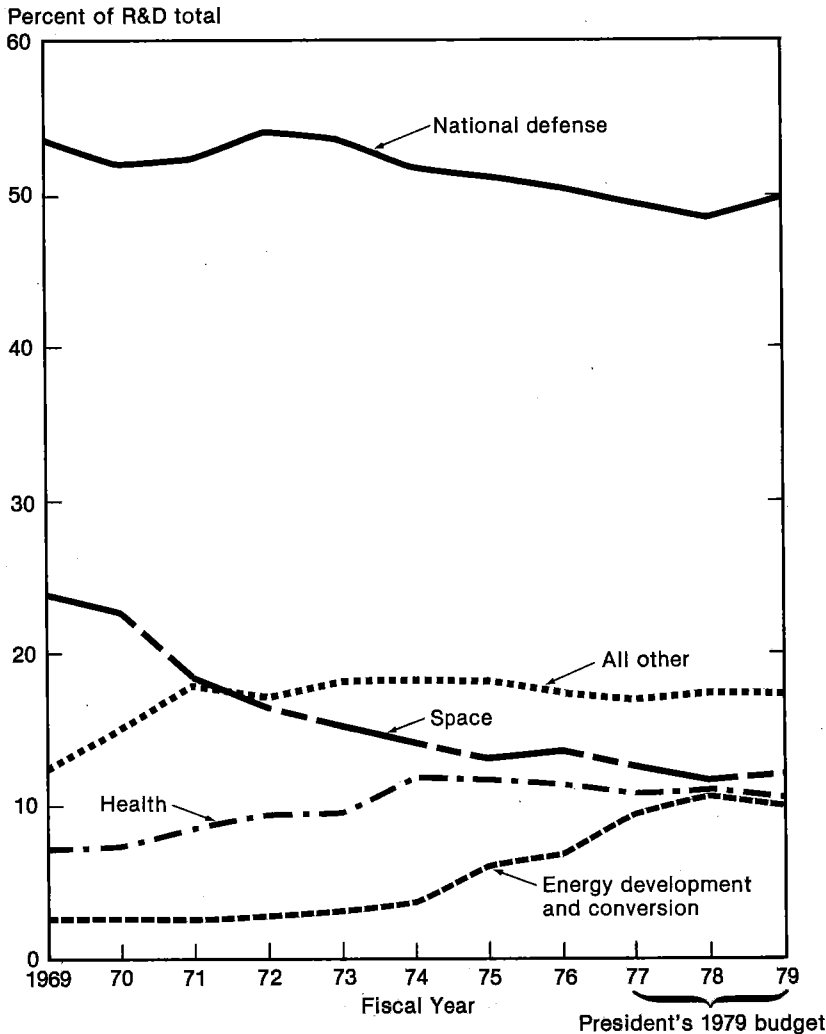
Program output consists of a series of published reports. Included among

these is a special summary report, *Science Indicators*, prepared biennially for the National Science Board and submitted to the President and the Congress. This report presents and analyzes sets of indicators that describe and measure changes in the national state of the science enterprise and in its international context. While informal feedback from users of these reports is received on a continuing basis, formally organized user surveys are carried out periodically. The most recent survey, in 1977, resulted in suggestions on how users' needs could be better met through different formats and presentations of existing data, additional data, or different methodologies applied to the existing or new data bases.

National R&D Resources

Information on total national R&D expenditures is developed from surveys of various sectors of the economy. Estimates are based on analyses of trends and factors pertinent to current funding patterns. These analyses showed that real growth in the Na-

Trends in Distribution of Federal R&D Obligations by Function: FY 1969-79



SOURCE: National Science Foundation

(3) Top management's decision to concentrate their R&D efforts on improving existing product lines for which additional basic research is not necessary.

(4) The decreasing company returns of R&D in terms of cost, business conditions, and risk taking.

The investigators point out that the decreasing proportion of industrial resources allocated to basic research reflects a broader problem, since similar cautionary trends are observable in applied research and development as well as in plant and equipment modernization. There appears to be an unwillingness by corporate management to commit resources to the future—i.e., take risks. (*Support of Basic Research in Industry*)

Academic. Academic science obligations totaled \$3.3 billion in 1977, up 13 percent over 1976. Nevertheless, the new total was still 20 percent below the amount obligated in 1967 in constant dollars. Federal support in this area has been characterized by sharp fluctuations during the past decade, ranging, in constant dollars, between a 12-percent decrease and this year's 6-percent increase. Aside from the effects of inflation, the declines result mainly from cuts in the amounts obligated for R&D plant, facilities and equipment for instruction, and fellowships, traineeships, and training grants.

Scientific and Technical Personnel

Utilization of scientists and engineers. Information on the employment, work activities, and characteristics of U.S. scientists and engineers is developed and maintained in the Foundation's scientific and technical personnel data system. This data base, which is maintained through various surveys, showed that employment increased at an annual rate of 2.5 percent to a total of 2.5 million between 1974 and 1976. This rate was significantly higher than

tion identified the following factors as the principal reasons for this decline:

(1) Improved understanding by top management of the strategic role of research, which leads to increased

control of research activities and the expectation of short-term results.

(2) Decreased Government support and increased Government regulation.

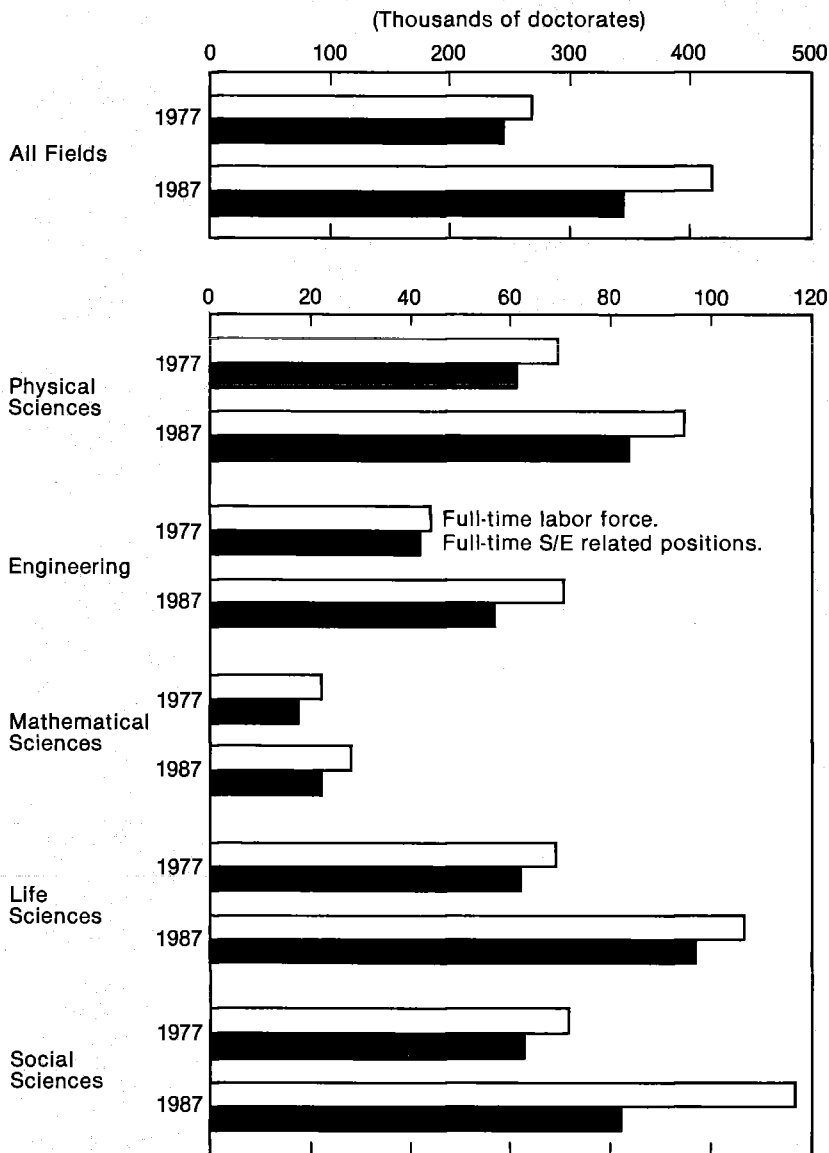
the 0.8-percent increase in total employment.

Employment of natural scientists increased by about 11 percent during this period; employment of social scientists and engineers increased by 7 percent and 2 percent, respectively. The difference between engineers and natural scientists in the rate of employment growth continues to highlight the changing relative demand for these work forces. During the decade 1966-76, the ratio of employed engineers to natural scientists declined steadily from 2.4 to 1.5. About three-fifths of all scientists and engineers were employed in private industry in 1976.

Doctoral scientists and engineers. Comparison of 1973 and 1977 characteristics of doctoral scientists and engineers reveals that in academic institutions the proportion of doctorates engaged primarily in teaching has declined while the proportion engaged primarily in research and development and other activities has increased. For all other types of employers, the proportion engaged primarily in research and development has declined. These compensating changes have kept the overall proportion of doctorates primarily engaged in research and development stable at 44 percent. The total number of doctorates primarily engaged in research and development increased at a rate substantially faster than non-doctoral scientists and engineers engaged in research and development. Thus, employers seem to be enriching their R&D staffs by taking advantage of the greater availability of Ph.D.'s.

Projections of the supply and utilization of science and engineering doctorates, 1982-87. The fourth of a series of reports begun in 1969 explicitly incorporates the effect of the market for highly trained technical personnel upon the numbers of science and engineering (S/E) doctorates awarded by American universities. The new projections reinforce the conclusion of the 1975 report that many new doctorate recipients are

Supply and S/E related utilization of doctorates*



*Includes postdoctorals
 SOURCES: National Science Foundation and National Research Council.

unlikely to find work related to their training through the mid-1980's. The projections indicate that in 1987 the proportion of doctoral scientists and engineers holding non-S/E-related

jobs might range from 11 percent in the physical sciences to 27 percent in the social sciences. The overall rate of non-S/E employment is projected at 18 percent.

NSF Planning and Evaluation

This program supports research and policy analysis to strengthen the Foundation's ability to plan and improve the support of research and science education.

The program focuses on strategic issues and policy options of specific concern to the Director of the National Science Foundation and to the National Science Board. During the past year studies concentrated on three principal concerns:

- An assessment of the national environment for the conduct of research and science education in the decade ahead.
- Means to increase public awareness and to facilitate public participation in the development of NSF policies and programs.
- A pilot study to determine the extent to which the results of basic research will be utilized in technological innovation processes.

In June 1978 the program published a series of papers describing R&D trends and factors expected to influence research in the years ahead. The papers included:

- "The Federal Environment for Research" by Willis H. Shapley and Don I. Phillips, American Association for the Advancement of Science.
- "Strategic Plans of Major Federal Research Supporters" by the NSF Office of Planning and Policy Analysis.
- "Trends in Industrial Research" by George E. Manners, Jr., and Howard K. Nason.
- "Federal Regulations of Universities: Purpose, Scope, Conse-

quences, and Policy Options" by Charles Kidd.

- "Science Is Too Important To Be Entrusted to Scientists" by Charles Adams Mosher.

The program continued its involvement in the planning and assessment of the National Science Board Forums, an experiment with public participation in NSF policy and programs. An important part of the experiment was a series of six regional public forums in which the public, business, and educational leaders met with members of the NSB and NSF staff to discuss research issues and opportunities. In fiscal year 1978 forums were held in Minneapolis, Denver, and Philadelphia.

In its ongoing effort to assess the major factors influencing the conduct of research, the program has begun studying problems associated with growing costs of performing research and with the utilization of academic research results by the industrial community. Key issues are those related to equipment and innovation. A major effort was initiated to assess the effects of inflation on the costs of performing research, with specific attention given to the costs of acquiring and operating increasingly sophisticated equipment. This continuing study will address alternative and innovative means of financing essential equipment. A second study sought to determine the extent to which basic research contributes to innovation in industry, as shown by patent process indicators. This work found that, to a high degree, industrial firms do utilize basic research results published in and available in the open scientific literature.

Evaluation studies provide the Director of the Foundation with information on the effectiveness, results,

and impacts of major NSF programs. They form the basis of oversight responsibilities in these areas and provide groundwork for budgetary or policy decisions about program expansion, curtailment, or reorientation. These evaluations focus on program output, using criteria based on program objectives. Program evaluations are designed internally; they are often carried out by external contractors.

In 1978 the evaluation of the Materials Research Laboratory (MRL) program was completed. This study looked at the differences between MRL's and other materials research groups and considered their capability to perform research, the nature and type of research done, and the productivity and merit of the research product. Although the primary focus of the study was on differences between MRL's and NSF-supported materials research at universities, groups supported by other agencies were also included in the study. Most of the findings were based on an analysis of data obtained from a review of publications by a select group of materials scientists. In addition, achievements submitted by the various university groups and the prestige of the materials research faculty at these universities were assessed, also by materials scientists. Other findings were based on analyses of resource data obtained from NSF files and directly from the universities.

The question of whether the MRL's are doing research that cannot be or is not being done as well as or as cheaply by project support was answered in part by evaluation results. It was shown that MRL's have a higher capability to perform research in that they gain researchers of higher reputation, have lower administrative costs, and hold equipment at least on par with non-MRL's. Further, it was found that MRL's differ from non-MRL's in that they are to a large extent carrying out research in different fields—some-what more purely experimental.

MRL's also tend to do a better job of reporting on their research. With reference to research coherence, no significant differences were detected be-

tween MRL's and non-MRL's in concentration of funding, annual rate of turnover, duration of research areas, and continuity of staffing.

Information Science and Technology

In 1977 NSF's Science Information Activities Task Force recommended far-reaching changes in the Foundation's science information program. These recommendations, many of which were implemented during fiscal year 1978, focus NSF attention on scientific theories of information and their application to scientific and technical information delivery systems.

During recent years information, and especially scientific and technical information, has become an increasingly important national resource whose rapid growth requires better methods to collect, correlate, organize, and use it. Meanwhile, escalating costs have provided additional motivation for understanding what can and cannot be accomplished in a practical way. To support these areas of basic and applied research, the Foundation established its information science and technology program during 1978.

Fundamental and Advanced Research

The development of standards and measures permits an objective assessment of the predictions of theory and a comparison of the performance of information systems and their component subsystems. In fiscal year 1978 the Committee on Data Needs of the National Research Council/National Academy of Sciences completed a study on national needs for critically evaluated physical and chemical data. It recommended that higher priority be given to quantitative data compilation and evaluation in order to support the Nation's R&D programs. The Com-

mittee also concluded that research should be done on the management and dissemination of quantitative data files.

Ohio State University, studying the general theory of information flow, defined a series of important measures that permit the analysis of information in terms of its utility to a decision-maker. The significance of this research lies in its development of a theoretical basis for quantifiable measures of document effectiveness and the efficiency of data base management techniques.

For decades national expenditures on scientific and technical information have been growing considerably faster than expenditures on research and development and somewhat faster than gross national product; they now total some \$13 billion per year. The production and use of this information involve scientists and engineers working worldwide under diverse economic and political conditions: It first appears in traditional and other forms of publication and distribution, winds up in vast library archives, is affected by regulative legislation including copyright law, and is used in governmental, private, and public organizations. Studies, surveys, and simulation models help to correlate and understand the activities and interactions of these sectors; they also provide the basis for short-term prediction of the probable effects of changes in economic conditions, legislative and foreign policy, and technological innovations.

A systems analysis of scientific and technical communication in the United States was completed during this past year by King Research, Inc., of Rock-

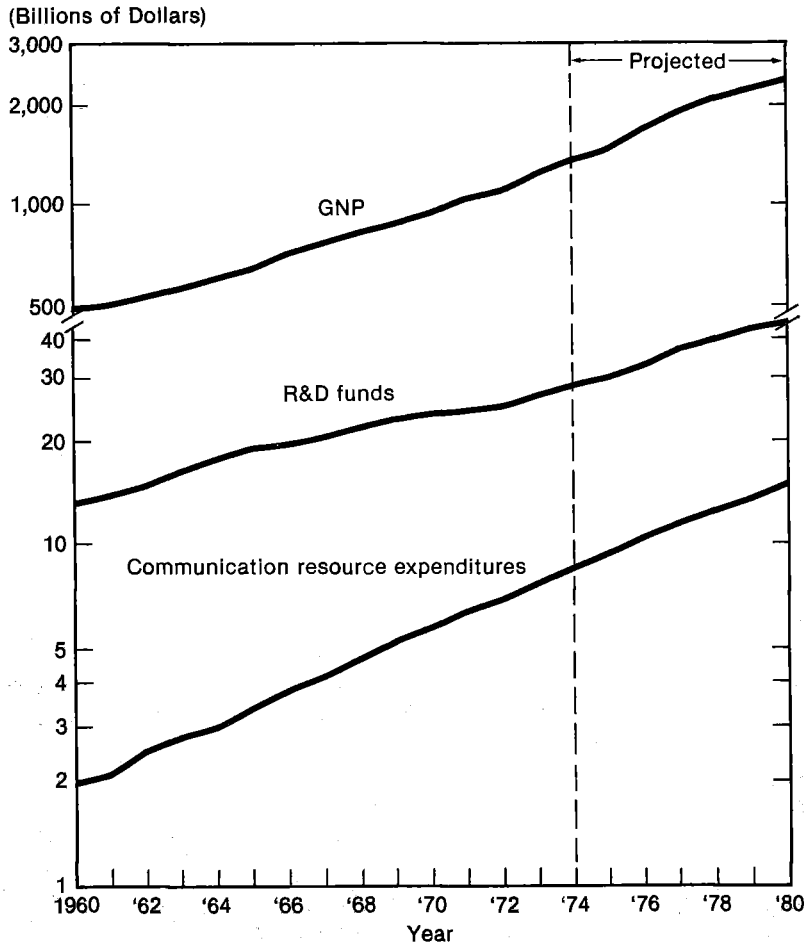
ville, Md. The analysts considered various phases of such communication, from the origination of information by an investigator to its ultimate user. They compared the existing paper-based system of scholarly communication with a hypothetical electronic alternative promising greatly increased speed, reliability, and convenience of information handling. Over a range of assumptions and for as far as the analysts could see into the future, they found virtually no difference in cost between the paper-based journal system and its electronic alternative.

Another study, by Arthur D. Little, Inc., attempted to see if major changes were required in Government programs related to scientific and technical information. The findings indicate that the kinds of contributions information resources are making to economic growth and progress are currently undergoing change. While still useful in promoting advances in physical and social science and technology, information resources are increasingly being used to solve social, economic, energy, and environmental problems. An important recommendation asserts the responsibilities of Federal agencies to make information systems available to State and local government agencies and to the general public, as well as to the scientific, academic, and business communities.

Research on Information Systems

As a study of the structure of information, a project at Lehigh University investigated underlying principles for the design of systems; this will permit retrieval of inferences and derivation of new relationships from the contents of two or more data bases. The project utilized machine-readable files on coal data, and attention was confined to coal-related energy. The design problem involved combination of two large and separate numerical data files to

Total science and technology communication resource expenditures, gross national product, and R&D funds, in current dollars (1960-1980)



SOURCE: Economic Report of the President, February 1975 GNP. (GNP) 1960-1974. National Planning Association (GNP) 1975-1980. King Research, Inc. Center for Quantitative Sciences (ST) Communication 1960-1980. R&D Funds 1975-1980. National Science Foundation, National Patterns of R&D Resources, 1953-1975 (NSF 75-307) (R&D Funds).

Growth of communications. This chart shows how national expenditures for science and technology communications have grown faster than either the GNP or national expenditures for R&D over recent years.

form a data base for coal-related decision support, and integration with a decisionmaking model. The project demonstrated that it is possible to generate new factual aggregates not apparent from either data base.

The utility of information depends on the abilities and limitations of people as information processors, both with regard to internal processing (which includes aspects of learning, memory, and information pattern rec-

ognition) and to the interplay between human sensory perception and the physical sources of information (such as books, computer terminals, and video displays). In fiscal year 1978 three additional geographically dispersed communities began trials of electronic information exchange, bringing the total number of trials under way to seven. Based on a research facility at the New Jersey Institute of Technology, these trials range from 12 to 18 months in scheduled duration, with the trial communities ranging in size from 17 to 40 members. An objective of each trial is to arrive at an assessment of how computer conferences and other forms of electronic information exchange affect the productivity of individuals who use them.

The first wave of assessments is scheduled to be made in fiscal year 1979. Meanwhile, experience with this new communication medium is accumulating at the rate of 2,000 user-hours per month, roughly eight times the highest level of usage previously reported for a computer conference system. Each month the research facility's 500 members transmit nearly 6,000 items and receive some 26,000 items in exchange.

The Electronic Systems Laboratory of the Massachusetts Institute of Technology is preparing an exhibit for the Massachusetts Governor's Conference on Libraries and Information Services (sponsored by the National Commission on Libraries and Information Science White House Conference). It will present an NSF-supported prototype computer interface for heterogeneous retrieval systems which: (1) allows users to express their requests in a common, easy-to-use language; (2) provides instruction so that even inexperienced people can use the interface effectively; and (3) automatically connects users to the appropriate retrieval systems and data bases and translates their requests from the common language to the appropriate languages.

International Programs

The Foundation's cooperative science activities include support for joint research projects and seminars/workshops, exchange of scientists, joint commissions for scientific and technological cooperation, and participation in international scientific organizations. Many of these activities operate under formal bilateral or multilateral agreements with foreign countries. In fiscal year 1978, NSF conducted programs under 16 such formal arrangements. In addition, cooperative activities were carried out under informal arrangements with another 22 countries.

The Foundation cooperates, formally and informally, with ten European countries. Under the program with Italy, a joint research project in cellular biology during the past year led to a new experimental technique that promises progress in understanding the molecular basis of embryonic development and cancer. A cooperative venture in materials research between U.S. and French scientists resulted in the formation of clusters of crystals—many for the first time, and some of a large size never before attained—which can contribute to improved performance and reduced cost in electronic devices and communication systems. In the Romanian program, research in atomic and plasma physics led to what may now be the best available method for investigating certain types of highly excited atomic systems.

Ongoing NSF cooperative activities with the Soviet Union take place under the U.S./U.S.S.R. Agreement on Cooperation in the Fields of Science and Technology. Areas of mutual interest include chemical catalysis, computer applications to management, electrometallurgy and materials, microbiology, physics, science policy, and scientific and technical information. During the fiscal year, 18 U.S. scien-

tists participated in exchanges, 44 joint scientific research projects were supported, and 97 joint publications were authorized.

In northern Colombia (one of nine Latin American countries in which NSF supported research with counterpart agencies), U.S. and Colombian geophysicists are studying an area that suffers one of the most intense rates of earthquake activity in the world. In 1976, during a 3-day period, 200 earthquakes were recorded in the area; the research is an effort to understand the mechanisms that produce such frequent earthquakes. In another Latin American joint project, scientists from the United States and Chile are studying the changes in chemical levels that can be expected in soils, crops, and

ground water irrigated and fertilized with wastewater and sludge. Scientists in Mexico and the United States are studying the chemical structure, physical properties, and extraction and processing variables of rubber from guayule. This arid-land plant, which grows in the Southwestern United States and northern Mexico, produces a latex very similar to natural rubber (*Hevea*).

Joint seminars in hydrometallurgy to explore new energy-efficient processes for extraction of minerals were held in Indonesia and the Philippines, two of nine cooperating countries in the Pacific region during 1978. A plant mycoplasma disease seminar in Taiwan allowed presentation of significant achievements and planning of followup activities by U.S. and Chinese investigators. New findings that may permit improvement in the survival and growth of plants at lower tempera-



Testing Soviet stainless steel. A section of a 750-pound high-nitrogen-steel ingot, sent to the United States under the Science and Technology Agreement on Cooperation in the Fields of Science and Technology, is hot rolled at Battelle Laboratories to evaluate its workability. (Photo by Battelle Columbus Laboratories)

tures were reported at a U.S.-Japan seminar on cold hardiness of plants.

As part of its Pacific area activities, NSF continued to provide partial support to the Committee on Scholarly Communication with the People's Republic of China (CSCPRC) under a contract with the National Academy of Sciences. Together with its Chinese counterpart, the CSCPRC facilitated the exchange of 13 delegations covering a wide range of scientific and technological subject areas.

Scientific cooperation with Africa and Asia is supported largely through Special Foreign Currency (SFC) programs. SFC countries are those in which the United States owns amounts of local currency in excess of its own normal requirements. During fiscal year 1978 NSF made SFC awards in Egypt, India, and Pakistan for research and related scientific activities, for international travel for scientific purposes, and for translations into English of foreign scientific and technological literature.

SFC-funded activities in Egypt included a project where solar energy specialists gave a short course in Cairo on the fundamentals, as well as present and future applications, of solar energy technology. The discussions were designed to assist the participants in the use of renewable resources in develop-

ing countries. In India an SFC award enabled U.S. and Indian scientists to study the basic phenomena of internal combustion engines and the application of these results to the problems of emission control. In another project, U.S. scientists participated in preparations for a major international effort, the Monsoon Experiment, in the Indian Subcontinent during late 1978 and 1979. In Pakistan, American and Pakistani scientists completed a survey of the geodynamics of Pakistan, which made new geologic data and maps available to the world scientific community.

NSF continued to support U.S. participation in several international, nongovernmental organizations. Among these organizations are the International Council of Scientific Unions, the Organization for Economic Cooperation and Development, and the United Nations Educational, Scientific, and Cultural Organization. Similarly, a major award in fiscal year 1978 was in support of the National Academy of Sciences' membership in the International Institute for Applied Systems Analysis (IIASA), a nongovernmental, multidisciplinary, international research institute located in Laxenburg, Austria. IIASA's recently published report comparing fusion and fast breeder reactors was the first such

comparison drawing upon contributions of both Eastern and Western scientists. The Foundation also makes travel awards to enable U.S. scientists to attend scientific congresses and meetings, obtain or exchange scientific information, and engage in international scientific activities. During 1978, 364 awards supported 616 U.S. scientists.

In addition to direct funding for research, NSF's international programs also support and conduct assessments of international science matters. For example, an NSF evaluation of the activities of IIASA indicates that: IIASA conferences are judged to be of high quality; IIASA has made considerable progress towards its original goals, but U.S. mechanisms for using IIASA research results require further development.

In August 1979 there will be a United Nations Conference on Science and Technology for Development (UNCSTD) in Vienna. During fiscal year 1978, NSF assisted the U.S. Coordinator for UNCSTD in the Department of State in preparations of the U.S. position for the conference by supporting individual studies related to conference agenda items and through the transfer of funds to the Department of State for preparatory activities.

Appendix A

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Appendix B

Patents and Inventions Resulting from Activities Supported by the National Science Foundation

During fiscal year 1978, the Foundation received 98 invention disclosures and made rights determinations in 51 inventions. The determinations, made in accordance with NSF Patent Regulations, included decisions to dedicate the invention to the public through publication in 18 cases, to transfer rights to other interested Government agencies in 3 cases, and to permit retention of rights by the grantee or inventor in 30 instances. At the end of the fiscal year NSF had entered into 4 additional Institu-

tional Patent Agreements for a total of 21. Licenses were received by the Foundation under 1 patent and 39 patent applications filed by grantees and contractors who had been allowed to retain principal rights in their inventions.

The following U.S. Patents issued from research supported by the Foundation:

No.	Title	Institution
4,016,331	Composite Polymeric Material Formed with an Epitaxial Crystalline Film of Polymeric Sulfur Nitride, and Method of Preparing Same	University of Pennsylvania
4,050,508	Controllable Heat Transmission Panels	Massachusetts Institute of Technology
4,055,783	Spark Source with Regulation of Spark Magnitude by Control of Spark Timing	Wisconsin Alumni Research Foundation
4,064,150	Synthesis of Isoprenoid 1,5-Dienes	University of Illinois Foundation
4,065,780	Tunnel Injection of Minority Carriers in Semiconductors	Cornell Research Foundation
4,066,821	Tungsten Carbide Tools Treated with Group IVB and VB Metals	Massachusetts Institute of Technology
4,067,823	Thallium (III) Reagents Supported on Montmorillonite Clay Minerals and Oxythallation Processes for Utilizing Same	Princeton University
4,068,214	Asynchronous Logic Array	Massachusetts Institute of Technology
4,069,418	Improvement on High Speed Optoelectric Sampling Head	University of Illinois
4,069,732	Electric Guitar	Massachusetts Institute of Technology
4,072,353	Thrust-Impact Rock Splitter	University of Missouri
4,076,866	Method of Growing Films by Flash Vaporization	Massachusetts Institute of Technology
4,077,020	Pulsed Gas Laser	Wisconsin Alumni Research Foundation
4,077,818	Development of Low Cost Film Polycrystalline Silicon Solar Cells for Terrestrial Applications	Southern Methodist University

4,078,167	Welding Shield and Plasma Suppressor Apparatus	United Technologies Corp.
4,084,041	Secondary Battery or Cell with Polysulfide Wettable Electrode -#2	Ford Motor Company
4,084,042	Secondary Battery or Cell With Polysulfide Wettable Electrode -#1	Ford Motor Company
4,084,943	Jet Membrane Gas Separator and Method	Grumman Aerospace Corp.
4,087,328	Purification and Immobilization of Sulfhydryl Oxidase	Research Triangle Institute
4,088,675	Production of Acyl Phosphate Salts	Massachusetts Institute of Technology
4,106,588	Mode Cancelling Composite Panel for Greater Than Mass- Low Transmission Loss in the Principal Speech Bands	Massachusetts Institute of Technology

Appendix C

Financial Report for Fiscal Year 1978

(in Thousands of Dollars)

Research and Related Activities Appropriation**Fund Availability**

Fiscal year 1978 appropriation	\$785,250	
Unobligated balance brought forward	7,216	
Adjustment to prior year accounts	<u>3,688</u>	
Fiscal year 1978 availability		<u>\$796,154</u>

Obligations

Mathematical and physical sciences, and engineering:		
Mathematical sciences	\$21,406	
Computer research	16,632	
Physics	59,858	
Chemistry	43,050	
Engineering	43,869	
Materials research	59,916	
Regional instrumentation facilities	3,010	
Industry/university cooperative research	<u>746</u>	
Subtotal, mathematical and physical sciences, and engineering		<u>\$248,487</u>
Astronomical, atmospheric, earth, and ocean sciences:		
Astronomical sciences	\$57,584	
Atmospheric sciences	56,415	
Earth sciences	34,065	
Ocean sciences	58,178	
Arctic research program	<u>5,339</u>	
Subtotal, astronomical, atmospheric, earth, and ocean sciences		<u>\$211,581</u>
U.S. Antarctic program		<u>\$48,447</u>
Biological, behavioral, and social sciences:		
Physiology, cellular, and molecular biology	\$57,636	
Behavioral and neural sciences	28,470	
Environmental biology	31,490	
Social sciences	<u>24,255</u>	
Subtotal, biological, behavioral, and social sciences		<u>\$141,851</u>
Applied science and research applications:		
Problem analysis	\$ 1,455	
Integrated basic research	620	
Applied research	18,057	
Problem-focused research applications	27,017	
Intergovernmental science and public technology	<u>7,962</u>	

Subtotal, applied science and research applications		<u>\$55,111</u>
Scientific, technological, and international affairs:		
International cooperative scientific activities	\$9,854	
Policy research and analysis	5,565	
Science resources studies	2,511	
Information science and technology	4,969	
NSF planning and evaluation	<u>883</u>	
Subtotal, scientific, technological, and international affairs		<u>\$23,782</u>
Program development and management		<u>\$48,695</u>
Subtotal, obligations		<u>\$777,954</u>
Unobligated balance carried forward		<u>\$9,878</u>
Deferral carried forward		<u>\$6,900</u>
Unobligated balance lapsing		<u>\$1,422</u>
Total, fiscal year 1978 availability for research and related activities		<u><u>\$796,154</u></u>

**Science Education Activities Appropriation
Fund Availability**

Fiscal year 1978 appropriation	\$73,200	
Unobligated balance brought forward	758	
Adjustment to prior year accounts	<u>354</u>	
Fiscal year 1978 availability		<u><u>\$74,312</u></u>

Obligations

Science education activities:		
Scientific personnel improvement	\$31,713	
Science education resources improvement	27,933	
Science education development and research	8,860	
Science and Society	<u>5,358</u>	
Subtotal, obligations		<u>\$73,864</u>
Unobligated balance carried forward		<u>\$8</u>
Unobligated balance lapsing		<u>\$440</u>
Total, fiscal year 1978 availability for science education activities		<u><u>\$74,312</u></u>

**Special Foreign Currency Appropriation
Fund Availability**

Fiscal year 1978 appropriation	\$4,900	
Unobligated balance brought forward	534	
Adjustment to prior year accounts	<u>60</u>	
Fiscal year 1978 availability		<u><u>\$5,494</u></u>

Obligations

Special foreign currency program:	
Research and related activities	\$4,349
Science information	<u>1,080</u>
Subtotal, obligations	<u>\$5,429</u>
Unobligated balance carried forward	\$5
Unobligated balance lapsing	<u>\$60</u>
Total, fiscal year 1978 availability for special foreign currency program	<u><u>\$5,494</u></u>

Trust Fund**Fund Availability**

Unobligated balance brought forward	\$3,785
Receipts from non-Federal sources	4,348
Adjustment to prior year accounts	<u>-34</u>
Fiscal year 1978 availability	<u><u>\$8,099</u></u>

Obligations

Astronomical, atmospheric, earth, and ocean sciences activity (ocean sediment coring program)	\$3,758
Gifts and donations	<u>5</u>
Subtotal, obligations	<u>\$3,763</u>
Unobligated balance carried forward	<u>\$4,336</u>
Total, fiscal year 1978 availability for trust fund	<u><u>\$8,099</u></u>

SOURCES: Fiscal Year 1980 Revised Supplementary Budget Schedules to the Office of Management and Budget. Fiscal Year 1980 Budget to Congress—Justification of Estimates of Appropriations.

Appendix D

National Research Centers Contractors

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AUI Member Universities:

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Harvard University
The Johns Hopkins University
Massachusetts Institute of Technology
University of Pennsylvania
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University of Michigan
Ohio State University
Princeton University
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Cornell University

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California Institute of Technology
University of California
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Colorado State University
University of Colorado
Cornell University
University of Denver
Drexel University
Florida State University
Harvard University
University of Hawaii
Iowa State University
The Johns Hopkins University
University of Illinois at Urbana-Champaign
University of Maryland
Massachusetts Institute of Technology
McGill University
University of Miami
University of Michigan
University of Minnesota
University of Missouri
University of Nevada
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Ohio State University
University of Oklahoma
Oregon State University
Pennsylvania State University
Purdue University
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Texas A&M University
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Utah State University
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