National Science Foundation

Thirtieth Annual Report for Fiscal Year 1980

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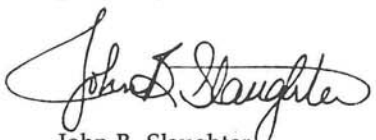
Letter of Transmittal

Washington, D.C.

DEAR MR. PRESIDENT:

I have the honor to transmit herewith the Annual Report for Fiscal Year 1980 of the National Science Foundation for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,



John B. Slaughter
Director, National Science Foundation

The Honorable
The President of the United States

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The Continuing Responsibility

For the National Science Foundation, fiscal year 1980 was one both of continued excitement and achievement in research as well as the beginning of some changes in how NSF is likely to address its responsibilities in coming years. It also marked the departure of three highly successful and respected leaders.

Richard Atkinson, Director of NSF since 1977 (and Deputy Director for 2 years before that), became Chancellor of the University of California at San Diego on July 1, 1980. George Pimentel, Deputy Director since 1977, returned to the University of California at Berkeley to become Director of the Laboratory of Chemical Biodynamics, also on July 1. And Norman Hackerman, who is President of Rice University, completed 12 years on the National Science Board, the past 6 as its Chairman.

Norman Hackerman has been succeeded as NSB Chairman by Lewis Branscomb, who is Chief Scientist for IBM Corporation. George Pimentel is followed by Donald Langenberg (who also served as Acting Director of NSF until my arrival).

But periodic successions of administrators—even when, coincidentally, they occur in a batch—should not obscure the central characteristic of NSF: its continuity, over 30 years, as a unique source of broad Federal support for basic science and engineering research. Certainly, reading through this year's *Annual Report*, with its overwhelming emphasis on the results of basic research, confirms the rich bounty of new knowledge resulting from our tradition of identifying and encouraging inquiry of the most challenging questions by the best minds.

NSF, of course, has important continuing responsibilities in addition to supporting basic research—as reflected, for example, in the reports on studies of innovation processes, risk analysis, or international cooperation in science. And this year's account of programs in science education illustrates how NSF stretches limited resources to serve a diverse and, ultimately, very large clientele by supporting innovative projects whose success can inspire subsequent adaptation by others.

This past year has also seen heightened introspection about the long-term continuing health of science and engineering—and what actions may be desirable to ensure it. In the summer of 1980 NSF, in conjunction with the Department of Education, prepared and submitted to the President a study on *Science and Engineering Education for the 1980s and Beyond*. This report documents shortages of qualified faculty in many engineering disciplines—notably the electrical and computer sciences. Certainly one of the problems that will concern the country in coming years is how to meet the pressing engineering education demands of the 1980s.

We also devoted considerable effort to reassessing the ways in which we are organized to identify, evaluate, and support research. As a result, several significant changes will occur at NSF in fiscal year 1981.

Throughout much of the 1970s NSF has been evolving a mechanism for supporting applied research, and we learned and achieved a great deal through such early programs as our ventures into solar energy and interdisciplinary studies. More recently we have conducted applied research programs that complemented the interests of some basic research programs and at the same time maintained a flexible mechanism for referring proposals from one to the other when a better fit was possible.

Our experience with basic and applied research

teaches us that the differences are not nearly as great as their names suggest. Certainly from NSF's point of view, funding decisions have been far less concerned with what a proposed project is called than with its potential contribution to developing new knowledge. Recognizing this, we intend to merge our applied research programs into the various research directorates. We expect that the somewhat wider range of interests than represented within disciplinary areas will strengthen the programs and make it easier for principal investigators to pursue important research topics even if that pursuit takes them from one part of the basic-applied spectrum to another. (Actually, this precedent is well established at NSF. Both engineering and materials science have long accommodated a broad range of basic and applied research within their disciplinary programs.)

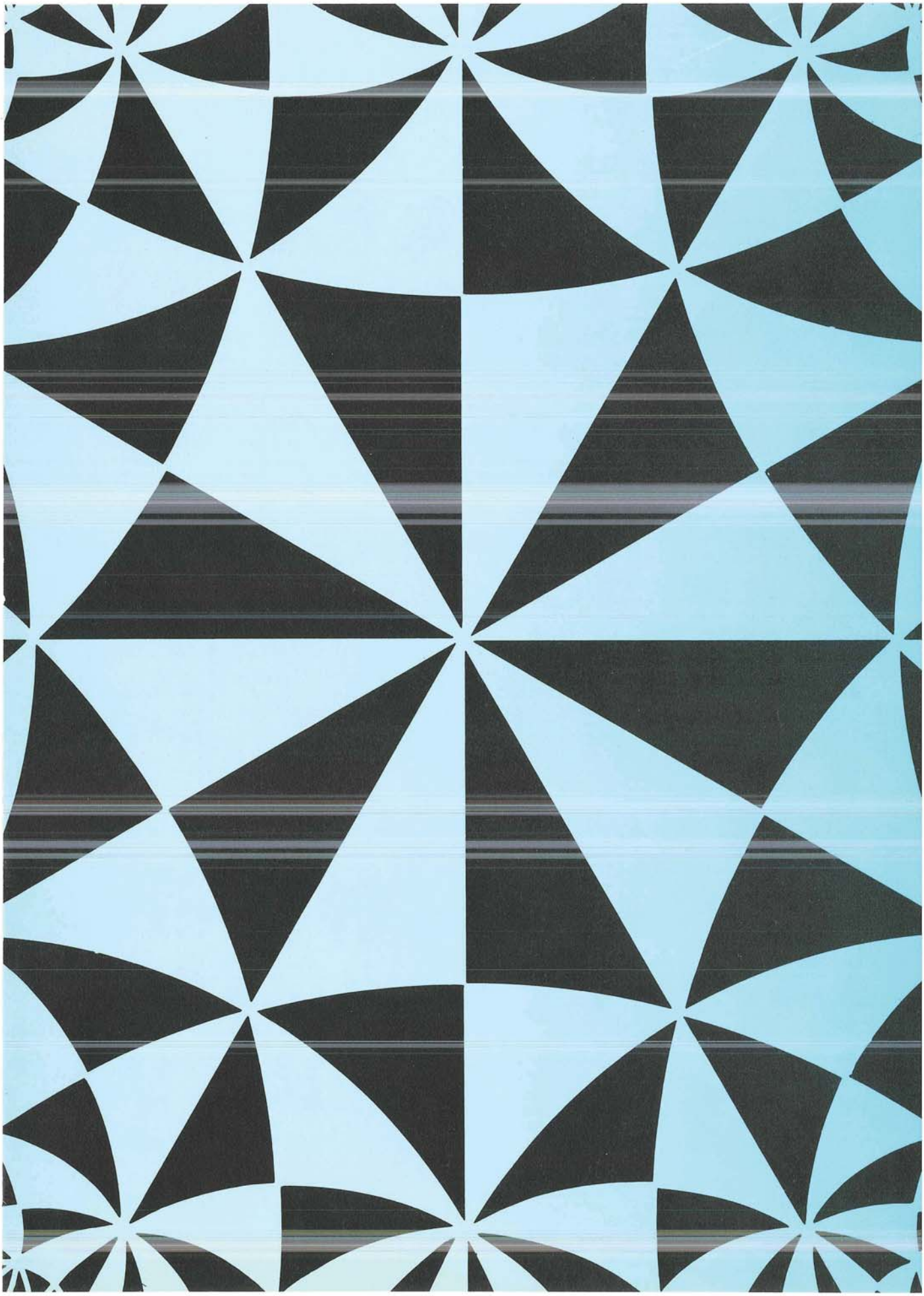
The other major change we will be making is the establishment of a separate directorate for the support of engineering research. We take this step primarily in recognition of the responsibility NSF has to ensure the health of engineering research as part of our overall mission. At the same time we are aware of the unique linkages between engineering research and industrial productivity and innovation. International competition—especially in manufactured goods—has become heated as other nations strive to match the level of our own technological strength. Many observers attribute the sluggish U.S. response to this competition at least in part to inadequate attention to engineering. We expect this new directorate, by virtue of its increased visibility and autonomy, to help focus attention on the pressing research agenda, on the role engineering can play in productivity and innovation, and on strengthening academic research capabilities.

I must emphasize that such steps do not imply any major shift in the allocation of our resources between basic and applied research or between the traditional and the engineering sciences. The House Science and Technology Committee recently stressed that our traditional core research programs "must be maintained as part of the Nation's effort to maintain world technological leadership and protect national security."

NSF plans nothing to alter that emphasis. New steps can, however, make us more agile in dealing with engineering and applied research, and we would hope to see a greater degree of mutual reinforcement between applied and basic research in both engineering and scientific disciplines.

We live in a far more competitive world today than we did 30 years ago when the Foundation was born. But competition, and the challenges it brings, is almost invariably associated with opportunities. Challenge, opportunity, and the imagination and ingenuity to make appropriate changes and adaptations—these are the very stuff of scientific and engineering enterprise. We as a Nation have in full measure all the requisite talents for pursuing and applying scientific knowledge, and I am confident that we will continue to do it very well in the years ahead.

John B. Slaughter
Director



Mathematical and Physical Sciences 1

Research in the Mathematical and Physical Sciences (MPS) has the objective of developing improved understanding of phenomena in the physical universe and providing the scientific base for future technological, economic, and social development of the Nation. To further this objective, research, most of which is basic in character, is supported across the disciplines of physics, chemistry, mathematics, computer science, and materials.

Progress in other disciplines of the natural sciences and in engineering has been and continues to be highly dependent on the mathematical and physical sciences. For example, advances in modern "state-of-the-art" instrumentation are subsequently used in a variety of sciences. Laser technology and computer systems are examples of developments that have opened totally new possibilities for the experimental sciences. The mathematical and physical sciences also provide the underpinnings for theory in the other disciplines by formulating new conceptual approaches to science.

The MPS disciplines continue to be unusually exciting and vibrant. Examples of developments in each MPS area follow and are described in greater detail in this chapter.

In elementary particle physics, quantum chromodynamics is the most promising current theory of the strong interaction—one of the four fundamental forces of nature. Precision measurements of four states of the bottom quark and its antiparticle, carried out at the Cornell Electron Storage Ring, are in close agreement with the predictions of this theory. A lively effort is under way to combine quantum chromodynamics with the Glashow-Salam-Weinberg model of the electromagnetic and weak interactions into a "grand unified theory" of three of the four fundamental forces (gravity is the fourth). This development presents the challenge for experimental physicists to devise experiments that will test the theory.

In chemistry, derivatives and transformation products of naturally occurring anticancer compounds, which should show both improved antitumor activity and reduced toxicity, are being synthesized with increasing regularity. New laser-excited matrix isolation fluorescence procedures have made possible more sensitive analyses of environmental pollutants. Success in these basic areas of chemistry will certainly lead to advances in our physical well-being as the research applications are developed further in industrial laboratories.

A problem in abstract algebra has just been completed with the construction of the last 2 of the 24 postulated sporadic finite groups. One of these, which is called the "Monster" because it consists of 10^{54} members, has generated particular excitement among mathematicians and has led to surprising connections with other, previously unrelated, areas of mathematics.

Modern submicron electronics technology has ushered in a new era of challenge and opportunity in com-

Table 1*
Mathematical and Physical Sciences
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Physics	349	$59.86	379	$61.66	408	$63.21
Chemistry	914	43.05	905	45.23	886	51.30
Mathematical Science	842	21.41	885	22.78	911	24.90
Computer Research	265	16.63	263	16.77	265	18.40
Materials Research	708	59.91	710	62.42	747	68.52
Total	**3,078**	**200.86**	**3,142**	**208.86**	**3,217**	**226.33**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

puter science. A major effort was begun in 1980 to establish a modern experimental research capability, based on this technology, in the Nation's colleges and universities. At the same time an expanded computer science research network (CSNET), which will link these capabilities across a broad spectrum of institutions, is being planned. Once completed, CSNET should increase the productivity of scientists and engineers at academic, industrial, and government laboratories and serve as a model to other disciplines.

In materials research, ultralow-temperature experiments are being refined toward the point at which theoretical predictions of a new state of matter can be tested. This "new" state is comprised of systems of spin-polarized hydrogen atoms that remain gaseous down to the absolute zero of temperature and condense into gaseous superfluid states at sufficiently high densities. At the same time, the fundamental aspects of metallic glasses continue under investigation. Because of their unusual properties, these substances have the potential for an eventual impact on modern society comparable to that of semiconductors.

The spectrum of support provided across the 36 research programs in the Mathematical and Physical Sciences ranges from projects involving one person to major facilities involving large numbers of investigators. The mode of support depends on the specific needs of each discipline and the requirements of the research proposed. Most awards assist individuals or small groups of faculty who, together with their graduate students and postdoctoral research associates, carry out projects in their own laboratories. This is the traditional style of basic research in the Nation's universities. But other institutional arrangements are necessary in some disciplines; the increasing cost of modern, sophisticated research equipment and facilities means that scientists must share their use. NSF therefore supports a number of national user facilities, including the Cornell Electron Storage Ring, the Indiana University Cyclotron Facility, the Synchrotron Radiation Facilities at Stanford, Wisconsin, and Cornell, the National Magnet Laboratory at Massachusetts Institute of Technology, and the Small Angle Neutron Scattering Facility at Oak Ridge National Laboratory. At these sites, scientists use equipment and facilities that would be unavailable on an individual basis. Most of the research at these facilities is conducted by university-based users who travel to the national laboratories to carry out experiments. In addition NSF supports 13 interdisciplinary materials research laboratories, a number of nuclear physics research laboratories, and other research institutes.

Unsolicited research proposals to conduct research are initiated by individual or groups of scientists who wish to undertake a specific project. They are submitted on behalf of these investigators by their institutions, primarily colleges, universities, and nonprofit research organizations. Proposals are then reviewed by members of the "peer" community (drawn from academic, industrial, and government institutions) who are expert in the area of research proposed. The principal criteria for evaluation are the scientific merit of the proposed research and the ability of the investigators to carry out that research. During 1980 some 5,300 research proposals were received and evaluated by more than 20,000 reviewers. Successful proposals ultimately resulted in support for the research efforts of more than 4,000 scientists. In addition, over 3,700 graduate students were given an opportunity to apprentice under the tutelage of some of the Nation's finest researchers. This involvement of our highest quality graduate students in research represents an important investment for the future of this Nation. NSF thus fills the dual roles of supporting forefront research and facilitating the continued flow of expert scientists into the pivotal disciplines that it serves.

Physics

Physics is at a stage where both experimental and theoretical results combine to suggest a new richness in our conceptions of the material universe. The current generation of high energy accelerators provides opportunities to expand knowledge of elementary particles, to explore the characteristics of nuclear matter, and to further elucidate electronic processes in close collisions. Great numbers of people are involved in large-scale experiments at these major facilities.

On a smaller scale, improvements in laser technology are leading both to a new generation of precision measurements in atomic physics and to the possibility of enhanced detectors for gravitational radiation. In theoretical studies, developments in renormalized gauge theories dealing with the electroweak interaction and in quantum chromodynamics dealing with the strong interaction seem to presage a grand unification of theories, with noticeable consequences even below the region of extraordinarily high energies. Among the themes emerging within the subfields and across subfield boundaries, one can identify the following:

- In particle physics, the most promising theory of the strong interactions is quantum chromodynamics (QCD). A lively effort is now being made to combine the Glashow-Salam-Weinberg model (for which these physicists shared the 1979 Nobel Prize in Physics) and QCD into a "grand unified theory" of the weak, electromagnetic, and strong interactions—three of the four fundamental forces of nature (gravity is the fourth). Such theories predict that the proton is unstable and that the strong, electromagnetic, and weak forces all have the same strength at energies of 10^{15} GeV. To achieve such high energy one would need a truly prodigious accelerator; more likely, physicists will be able to look to astrophysical evidence of the events that occurred just after the Big Bang.

  Experimental particle physics is dominated by accelerators, such as the Cornell Electron Storage Ring where studies of the "b" quark are currently emphasized. Detectors that record the particle collisions in such experiments are large and complicated, usually being fabricated by collaborations of university user groups. New accelerator designs await development. Giant, passive detectors for very high energy cosmic rays impinging on the earth from space are also coming into use.

- Experimental nuclear science uses a variety of accelerators. New and upgraded facilities provide beams of heavy ions from 20 MeV/nucleon to several hundred MeV/nucleon. These accelerators permit studies of nuclei under extreme conditions and may yield new forms of dense matter as well as new configurations of nuclei. Continuing equipment development will lead to beams of higher energy definition and higher intensity, both for heavy particles and for electrons.

  Results of these experiments are compared with an equally wide range of nuclear theories and models. It is particularly challenging to bridge the gap in theories between the short and longer intranuclear distances. Nuclei represent a microscopic laboratory sensitive to the details of this transition region.

  Significant progress is being made in the case of heavy ion collisions and the statistical treatment of the shell model. Progress in dealing with the nuclear many-body problem has implications as well for other fields.

  Advances in precision spectroscopy throughout the electromagnetic domain are returning atomic physics to its former role as a preeminent testing place for the effects of relativity, quantum electrodynamics, and electron correlation. These and closely related developments lead to a variety of tests for departures from well established fundamental symmetries and invariances; they also provide new opportunities for determining numerical values of fundamental atomic constants.

  On the experimental side, recent progress reflects rapid utilization (or development) of new technologies. Advances in laser technology—especially improved control over resolution, stability, intensity, and spectral range—have opened totally new experimental possibilities. Moreover, atoms, molecules, and their ions can now be stored for long periods, cooled to low temperatures, and studied individually and in small groups.

- In gravitational physics, broadly based theoretical programs continue to explore the consequences of general relativity. Computer simulations model the production of gravitational radiation by stellar collapse to black holes or neutron stars, by collisions of black holes or neutron stars, by collision of black holes with normal stars, and by supernova explosions. Analytic work in relativistic astrophysics studies black holes, the binary pulsar, galactic structure, and cosmology. An especially important collaboration is expected to grow between gravitational and particle theorists in developing a quantum theory of gravitation. Creating such a theory is the greatest challenge to theoretical physics during this century.

  Experimental programs continue to emphasize gravity-wave detection with resonant bars and, increasingly, with free masses (laser interferometers). Other experimental programs are increasing the precision of measurements within the solar system. Examples include the retardation of radar signals passing near the sun; advance of the perihelion of Mercury, Venus, and Mars; gravitational deflection of microwave signals from space probes; solar oblateness; and the variability of the gravitational "constant" over space or time.

Cornell Electron Storage Ring

The most exciting results of 1980 in understanding new states of matter were obtained with the newly converted Cornell Electron Storage Ring (CESR). Initial results include observation of four states of the family of particles made up of the b, or bottom, quark and its antiparticle, the b. Precision measurements of the energies of this fifth quark, which are in close agreement with predictions

made for it by the strong-interaction theory, indicate the familial resemblance of the new quark (b) to the four already known—the up (u), down (d), strange (s), and charm (c) quarks. These far-reaching results confirm the importance of this recently revamped Cornell research program in elementary particle physics.

CESR is an 8 GeV × 8 GeV electron-positron colliding-beam accelerator. In the summer of 1977 NSF authorized Cornell to convert its 12-GeV synchrotron to this new configuration under the direction of Boyce D. McDaniel. This major upgrading included installation of a second ring of bending magnets and power supplies in the tunnel housing the original synchrotron, fabrication of a major particle detector at one of the intersecting regions, and new computer capability for the laboratory.

Cornell shut down its synchrotron in October 1977, and the entire laboratory enthusiastically redirected its efforts to the conversion, completing the project about six months earlier than planned. The faster schedule resulted in overall cost savings as well.

First beams were injected into the storage ring on April 1, 1978, followed by adjustments to achieve collisions between the electrons and positrons circulating in opposite directions in the ring. The research program began in October 1979 on a part-time basis. Three states of the fifth quark were seen during this phase, even while final conversion was still under way. On June 1, 1980, less than three years after it was authorized, CESR was completed, providing a unique facility for studies in this energy range by physicists from throughout the Nation.

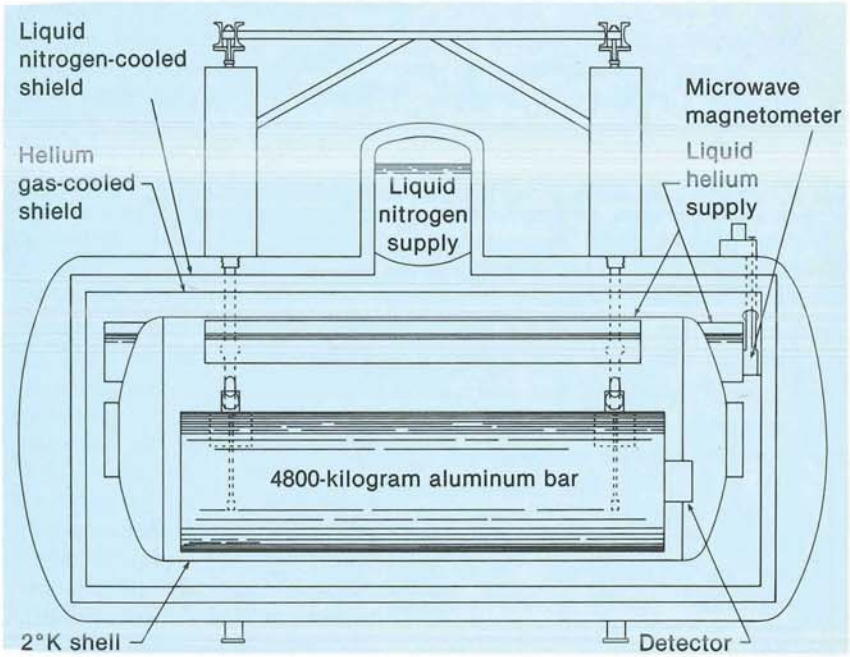
Search for Gravitational Radiation

One of the profound, but as yet unconfirmed, consequences of Einstein's theory of general relativity is the propagation of fluctuating gravitational forces in the form of waves. Such gravitational radiation plays a part as well in all alternative theories of gravitation. It is now firmly believed to be important in determining the course of significant events in the evolution of the universe, such as the formation of black holes.

The direct detection of gravitational waves would dramatically confirm the dynamic nature of gravitation, and closer study would eventually provide a way to study astrophysical processes which are not accessible to the usual tools: radio, optical, X-ray, or gamma-ray telescopes. But gravitation is the weakest of the four fundamental forces of nature, and gravitational waves are thus uniquely difficult to detect—the most sophisticated and sensitive equipment assembled has not yet given unequivocal results.

The strength of a gravitational wave is indicated by the momentary change that it would cause in the length of an imaginary antenna consisting of two massive, freely falling bodies. For example, the waves resulting from the formation of a black hole at the center of our galaxy with a mass comparable to that of the sun might change the antenna length by about five parts in 10^{18}. This "strain" is equivalent to changing the distance to the moon by 4×10^{-10} meter, or about one thousandth of the wavelength of light.

Surprisingly enough, it appears possible to make detectors sensitive enough to detect such a faint effect. The pioneering efforts of Joseph Weber at the University of Maryland led in 1974 to simultaneous observations by several geographically separated experimental groups whose massive aluminum cylinders attained strain sensitivities of about 10^{-16}. It is now



Cryogenic receiver. Gravity waves—a fundamental physical phenomenon predicted by Einstein's theory of general relativity—have never been directly confirmed. This new, low-temperature detector—shown in cutaway view—now operating at Stanford University is by far the most sensitive yet constructed and is setting interesting limits on possible astronomical sources of this elusive radiation.

recognized that although some gravitational wave events might have been detected if a sensitivity of 10^{-18} had been achieved, successful gravity-wave astronomy will almost certainly require detectors with sensitivities of about 10^{-21}.

Since the early seventies several groups have been exploring the use of low temperature techniques for more sensitive detectors. Low temperature directly reduces one of the most important sources of noise in the detectors, the random thermal fluctuations in the antenna itself. At low enough temperatures it is also possible to use the unique properties of superconductors to build almost noise-free circuits and amplifiers with sensitivities approaching limits defined by the quantum mechanical nature of the physical world.

Such a detector, built by William Fairbank and his group, is now operating at Stanford University. The 4800-kilogram antenna is cooled to 4.2°K by a surrounding liquid helium bath. The oscillations of the antenna are detected by a novel resonant superconducting transducer and a specially developed high-sensitivity Josephson-junction amplifier. The construction of the detector was a unique technical achievement, and its sensitivity, 2×10^{-18}, is approximately 50 times better than that of previous antennas. The Stanford group intends to carry out simultaneous observations with other groups when more antennas of comparable sensitivity are operating.

Booster at Stony Brook

The processes that occur when two atomic nuclei collide with high energy pose a rich intellectual challenge and suggest some tantalizing opportunities. Gentle collisions allow one to probe the nuclear surface, whereas more violent impacts involve the entire nucleus. Nuclear states never seen before may be formed when a few nucleons (particles in the nucleus, such as protons or neutrons) are transferred in the collision. Sometimes much energy is transferred but the impinging nucleus reemerges intact. Strange patterns in the emission angles of light and heavy fragments suggest nuclear hot spots or jets. With complete fusion of the nuclei, properties of nuclear matter such as viscosity and superfluidity can be investigated. Changes in nuclear shape occur, and the maximum angular velocity that a nucleus can have before fission may be found. Exotic new nuclei may be produced, and the intriguing possibilities of very heavy nuclei having a voracious appetite for neutrons may be pursued.

A powerful booster accelerator is being assembled at the State University of New York-Stony Brook for heavy-ion nuclear physics. When completed in 1982, it will be the highest energy device of its type to be operating and will allow physicists to extend their research over a wide range of phenomena in nuclear physics. New types of atomic physics and solid state physics experiments will also become possible.

The new part of the acceleration system, called a superconducting LINAC, will boost the energy of ions (charged particles) coming from Stony Brook's 9-million-volt tandem electrostatic accelerator to as much as 500 MeV. The energy is variable and depends on the mass and charge of the accelerated particles. Most of the work will be done with nuclei of mass number up to 100 times the mass of a proton. At such masses, achievable energies are great enough to overcome the electrical repulsion between projectile and target nu-

Accelerator booster. Scientists at the California Institute of Technology assemble a "split-loop resonator" intended for use as part of an upgraded accelerator at the State University of New York at Stony Brook. The unusual electricity-conserving device, equipped with 37 of these superconducting resonators, will accelerate heavy atomic nuclei to 10 percent the speed of light, permitting new types of experiments of important physical phenomena.

cleus so these may come within range of the enormous nuclear forces.

The superconducting split-loop resonators which are the heart of the booster accelerator were developed by physicists at the California Institute of Technology in collaboration with Stony Brook. Thirty-seven of these resonators will be set in a row. The frequency of oscillation and the spacing of the gaps at the ends of the loops are such that a short bunch of high speed ions from the tandem arrives at each gap just in time to be pushed forward by the electric field, finally achieving about 1/10 the velocity of light.

To make this possible with low power usage, the entire resonator is made of copper, plated with lead, and is run at liquid helium temperature (4.2°K). The lead is superconducting at this temperature, so each resonator requires only a few watts of power. Many technical problems had to be overcome to stabilize the natural frequencies, to preserve superconductivity, to achieve low power loss, and to lock all resonators to the same phase. The short pulses (60 per second), variable energy, variable ion species, and very small beam size make this an ideal device for nuclear experiments.

Precision Measurement of Electrons

Many advances in our understanding of the fundamental laws of science are inextricably linked to advances in precision measurement. Such measurements provide a quantitative foundation for our basic assumptions regarding the behavior of matter and test their validity over wide ranges. Recently, Hans Dehmelt, assisted by Robert Van Dyck, Jr., and Paul Schwinberg, of the University of Washington, measured the key properties of the electron to a new accuracy by isolating a single electron from the perturbations of other particles or atoms. To do this they insert one slow-moving electron in a "trap" consisting of electric and magnetic fields impressed on an ultrahigh vacuum container; the particle is then stored for several weeks while it is isolated from virtually all extraneous influences.

Once the electron is stored, its orbits within the confining magnetic field can be measured with very high precision. This yields a much improved value for the constant (termed the "g-factor") that relates the electron's magnetic moment to its mass, charge, and spin. Dehmelt's new value of g, accurate to eleven significant figures, is the most accurately measured parameter of any elementary particle. A not inconsequential corollary of this measurement is that, at least to this accuracy, all electrons really seem to be identical. The quantity g also has a theoretical value, calculated from quantum electrodynamics, the basic theory describing the electron; that result agrees closely with Dehmelt's latest value. This provides the most stringent check of a prediction of any theory in science.

The results of this measurement of g can also be compared with those found by Arthur Rich at the University of Michigan with a different method using fast-moving electrons. However, this comparison requires an adjustment for electron velocity based on the theoretical framework of special relativity. The agreement then found between the two experiments serves as the most accurate check yet made of the assumptions and predictions of special relativity.

The University of Washington group is working on two extensions of this experiment. One is studying single positrons (the antiparticle of the electron) to see if their properties are indeed those predicted by current theory. First results show that a positron is in all respects similar to an electron except for the sign of its electric charge. The group also plans to modify the trap itself to allow several orders of magnitude of new precision to be achieved.

Chemistry

Chemistry continues to provide a steady stream of research accomplishments to support its pivotal position in U.S. basic research. As the scientific tools of the chemist have increased in scope and diversity, the scientific skills of the chemist have been challenged to search for the most important problems to attack. There is no end to the number of problems; there is only the task of establishing priorities as to which deserve the initial attention.

The answers that chemists seek range from questions concerning the most microscopic detail of electrons in molecules to the development of a strategy for the most efficient path for the synthesis of a molecule of important biological consequence. These answers provide the foundations for the synthesis of new molecules with predictable structure and function relations. NSF's programs in chemistry provide resources for more than 800 research groups. In addition, more than a thousand graduate students and 600 research associates also participate in these research activities.

The ability of chemists to use the complex molecules of nature as targets for synthesis is evident in the successful total synthesis of the complex natural product streptonigrin (described later in this section, as are

the other research projects mentioned briefly in this introduction). The synthetic challenge in this molecule lies in the mutual incompatibility of the functional groups that are attached to the aromatic rings. Because of this problem a careful staging of the synthetic steps in the synthesis was crucial to its implementation.

Chemistry is not restricted to the use of intricate or complicated molecules as targets of creative investigation. Indeed, the small molecules, especially the oxides of carbon, are of fundamental significance in the use of coal as a raw material for production of fuels and "petrochemicals." The oxides of carbon are also intrinsic to life-sustaining processes. Even after a century of modern chemistry the carbon-oxygen bond remains a target for scientific inquiry because it is involved in so many scientific issues of direct relevance to human needs. This is exemplified in the research on carbon monoxide as a reducing agent in synthetic chemistry with the aid of catalysts based on iridium and rhodium compounds.

From these examples one can see that the transformation of molecules is the goal of the chemist, and the success of chemistry depends on a steady stream of contributions from diverse research groups. Structure, bonding, and theory provide the basis for rational chemical synthesis. The new types of multiple bonding in organometallic chemistry have had a profound influence on the chemical architecture of new catalysts. This research often is a synergistic process in which progress in one area complements that in another.

Finally, we would be remiss if we did not point out the role of modern instrumentation in all areas of chemistry research. None of the projects highlighted on these pages could have succeeded without the availability of well equipped modern laboratories with state-of-the-art instrumentation. Our final report—on toxic substances in the environment—is an example of research made possible by the availability of a new light source, the laser, and the very fast detection and timing instrumentation of modern electronic devices.

The Total Synthesis of Streptonigrin

Streptonigrin is an unusual fungal metabolite which has shown considerable promise as an anticancer agent. This compound was first isolated and characterized about 20 years ago and was found to have a unique tetracyclic chemical structure. Clinical studies on a variety of human tumors have been conducted both in this country and in the Soviet Union. Streptonigrin has been found active against lymphoid malignancies when administered either orally or intravenously and is as effective as the nitrogen mustard chlorambucil for treatment of lymphoid leukemia and Hodgkin's disease. However, streptonigrin shows a relatively high degree of toxicity, which particularly manifests itself in the form of severe bone marrow depression in treated patients. Considerable effort has been expended by a number of research groups over the past 15 years to prepare analogs and derivatives of streptonigrin having enhanced antitumor activity and reduced toxicity.

Investigators under Steven M. Weinreb at Pennsylvania State University have now completed the first total synthesis of this complex natural product. This research is significant for several reasons. It more clearly defines the chemistry of streptonigrin and related compounds. Surprisingly, little work has previously been reported regarding various transformation products and derivatives of the natural product. This research also will presumably make available synthetic derivatives of streptonigrin not otherwise readily obtainable that may conceivably show improved clinical anticancer properties. Some spinoffs of significance in the area of synthetic organic chemistry have also resulted. In particular, new reactions have been developed for use in synthesis of a variety of other medicinally useful naturally occurring compounds.

Synthesis Gas as a Reducing Agent

The primary product of the industrial gasification of coke (a coal residue) with steam and oxygen is a mixture of carbon monoxide and hydrogen of widely varying composition, depending on the conditions used. Because many chemical processes need hydrogen as a reducing agent, this mixture, commonly known as synthesis gas, can be further treated with steam over a metal catalyst. In this way the CO component of the mixture, combining with the steam's oxygen, is converted to CO_2, and the steam's H_2 is freed (the water gas shift reaction); the byproduct CO_2 is then separated, leaving the hydrogen for further use.

Catalytic reductions using H_2 are of course well known. Several years ago Rowland Pettit of the University of Texas demonstrated that in certain cases similar catalytic reductions can be brought about with CO and H_2O as the reducing agent. He has now discovered a homogeneous catalyst system which, for certain reactions, allows the direct use of commercial synthesis gas as the reducing agent. Furthermore, the reductions can proceed using each component (CO and H_2) in proportion to their initial partial pressures, thus allowing the direct use of any composition of synthesis gas. This discovery constitutes an important contribution to basic knowledge of chemical reactivity, and it also provides the basis for greater industrial utilization of coal as a pre-

cursor of important chemical and pharmaceutical intermediates.

The reactions studied are electron transfer type reductions typified by the reduction of nitroarenes to aminoarenes, and the catalysts employed are metal carbonyls used in conjunction with a base. In the catalytic cycle it is presumably the anionic metal hydride that is the principal electron-donating species. With H_2 alone as the reducing agent, the hydride is produced by one reaction path; if CO is used it is produced by a different reaction.

The objective of Pettit's work was to obtain a system that uses both paths simultaneously. He has found that the various metal carbonyls, which were shown earlier to be effective catalysts for the reduction of nitroarenes to amines with CO as the reducing agent, display widely divergent behavior when H_2 or mixtures of H_2 and CO are used. Thus, one iron compound, a very active catalyst for reduction of nitroarenes with CO at 25°C, was completely inactive at this temperature when H_2 was employed. Another, an osmium-based catalyst, was active with CO as the reducing agent and was also active with H_2 in the presence of a base. Moreover, it was also found to be an active catalyst when mixtures of CO and H_2 were used, each in excess; unfortunately, analysis at the end of the reaction indicated that only the CO component of the mixture was used for the reduction.

However, using 1:1 mixtures of CO and H_2 with iridium and rhodium catalysts, he found that reduction of nitrobenzene to aniline occurred with use of both the CO and H_2 components. At lower temperatures with each catalyst system, there was a preference for use of the CO component, but as the temperature of the reduction was increased the relative consumption of hydrogen was also increased. Although with the iridium catalyst there remained a preference for CO consumption even at 187°C, the rhodium catalyst at 137°C produced almost equal use of CO and H_2 in the reduction.

Strong Metal-to-Metal Bonds

Atomic elements are linked to one another, in molecules, by chemical bonds, and the strength, number, and orientation of these bonds is a key determinant of molecular structure and chemical reactions. The most highly multiple bonds known for any chemical elements are quadruple bonds, first recognized between pairs of rhenium atoms by F. Albert Cotton of Texas A&M University in 1964. In recent years he has extended our knowledge of the nature and strength of these binding forces by studies of very strong, multiple bonds between atoms of the transition metals.

We now know that such bonds, or closely related ones, are formed by a larger fraction of the transition elements than previously realized. At least nine of the transition metals have now been shown to form metal-to-metal bonds with at least partial multiple character, and quadruple bonds occur between atoms of chromium, molybdenum, tungsten, and technetium. There are hundreds of compounds of molybdenum containing such bonds and a considerable number of compounds of rhenium and chromium. Tungsten had not previously yielded the abundance of such compounds that might have been expected by extrapolation from the chemistry of chromium and molybdenum, which are the two lighter elements in the same group of the periodic table. Recently, however, through the synthetic work of Richard R. Schrock and coworkers at the Massachusetts Institute of Technology, a considerable number of new compounds with tungsten-tungsten quadruple bonds have become available.

The quadruple bonds between chromium atoms are unique in their sensitivity to the introduction of additional ligands (chemical groups attached to the central atom) in axial positions. While this phenomenon is interesting in itself, and has been the subject of a great deal of experimental and theoretical study, it has proved useful as a tool for examining a phenomenon of still wider importance. Aliphatic chlorocarbons, such as CH_2Cl_2 (methylene chloride) and $CHCl_3$ (chloroform) in particular, are widely used as reaction solvents, and it is presumed that their ability to solvate at least certain solutes is a result of very weak donation of lone pair electrons on the chlorine atoms.

Such donation has been suggested from time to time in connection with reaction mechanisms, but, there has never been any direct evidence of it. Now such evidence has been obtained for the first time, for a dichromium compound that crystallizes with methylene chloride. There is in this compound a pair of chlorine and chromium atoms separated by a distance of 3.35 angstroms. From this distance alone one would be unable to draw any conclusion; it might well be regarded as simply a nonbonded contact. However, the Cr-Cr distance in this substance is increased by 0.07 angstrom, which is nearly half as much as it is increased when the oxygen atom of an ether molecule, which is undoubtedly bonded to the chromium atom, occupies the same position.

Thus, the Cr-Cr quadruple bond acts as a sensor of electron pair donation and signals that such donation is indeed occurring. Substantial theoretical advances have been made in the past few years whereby a detailed and accurate understanding of the electronic structures of these strong, multiple metal-to-metal bonds has been evolved. Such information is vital if use of the transition metals as catalysts of unprecedented quality is ever to be realized.

Laser-Excited Fluorometric Analysis

The liquefaction and gasification of coal for the production of petroleum and natural gas substitutes, as well as the combustion of fossil fuels, produce as byproducts significant quantities of chemical compounds known as polycyclic aromatic hydrocarbons (PAH). Unfortunately, a number of them are mutagens or carcinogens in animals, a problem compounded by the difficulty of identifying PAH contaminants in the environment.

A promising technique for such analyses is molecular fluorescence spectroscopy, which has been widely used in the analysis of polycyclic hydrocarbons. However, fluorescence methods, though they are capable of detecting substances at the parts-per-billion concentration level, are generally not selective techniques and not easily applicable to analyses of complex samples.

Recently, though, Earl L. Wehry and his group at the University of Tennessee have been able to enhance the selectivity of fluorescence analysis without sacrificing its inherent sensitivity. A special form of sample preparation, called matrix isolation, is used, and laser techniques are employed to excite the molecules to high energy states. The sample molecules are vaporized by heating, then mixed with a large excess of an "inert" gas, such as nitrogen. The gaseous mixture is deposited onto a cold window (at a temperature of −435°F), the sample excited by the laser, and the fluorescence (the light emitted by the excited molecules as they return to their original states) of the deposited solid measured.

The beauty of the laser technique—in this case a tunable dye laser—is that it emits intense light whose exact energy can be chosen. By carefully selecting this wavelength to excite the fluorescence, the chemist can obtain a highly characteristic and reproducible spectrum that serves as a "fingerprint" for individual compounds—even in complex mixtures containing as many as 50 different PAH. This extremely high sensitivity permits both identification and quantitative measures of individual PAH's.

When fluorescence emissions of individual compounds in complex mixtures overlap, time-resolution procedures frequently can resolve individual sample components. This technique is based on the fact that the excited states responsible for fluorescence often have different lifetimes. Hence, if two overlapping fluorescences reflect excited states with different lifetimes, then measurement of the spectrum as a function of time will reveal the presence of multiple fluorescences.

The measurement of time-resolved molecular fluorescence spectra is very challenging, because the lifetimes of fluorescent-excited states of PAH are typically in the range of billionths of a second. But such transient signals can now be directly studied as a result of a decade's basic research that has led to development of lasers with light pulses shorter than the fluorescent lifetime. The use of such a laser source, coupled with very fast light detection devices, make the measurement of time-resolved spectra feasible.

In addition to enhancing the selectivity of fluorescence analysis, both matrix-isolation and time-resolution techniques have increased the sensitivity of the method such that concentrations of fluorescent species in the sub-parts-per-billion range are detectable. In favorable cases, quantities of individual compounds less than a trillionth of a gram can be detected by these techniques. Thus, the laser-excited matrix-isolation of fluorescence procedure is applicable to some of the very difficult problems in environmental pollutant analysis.

Mathematical Sciences

The mathematical sciences program has two major subdivisions: core mathematics and applied mathematical sciences. Core mathematics differs from the physical sciences in that it does not deal directly with objects and events of the physical world. Rather, it is a structure dealing with objects of its own perception, these being created in the human mind and transmitted to the external world by graphic symbolism. Applied mathematics is a more ambiguous term. It is used by some to refer to mathematics created with the end of understanding the world around us. But a second usage is to call mathematics applied whenever it is used to further our understanding of specific phenomena which we observe in the real world. Thus the term applied mathematical sciences has come to refer broadly to areas of scientific knowledge heavily saturated with mathematical structures, such as classical mathematical physics, operations research, statistics, certain elements of computer science, mathematical economics, and mathematical biology.

Mathematical analysis began with the invention of the calculus in the 17th century and continues to attract more mathematicians, both pure and applied, 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 to-

pology. 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.

In terms of dollar obligations, core mathematics represents about 75 percent of the NSF mathematical sciences program and applied mathematics about 25 percent. In the instance of core mathematics, NSF provides most of the Federal support for research. While it is difficult to obtain precise estimates of the total support by NSF relative to that of other agencies because of administrative and definitional differences, available data indicate that NSF accounts for about 70 percent of the total Federal support of the mathematical sciences, and about 98 percent of the support of core mathematics.

The health of mathematics in the United States is good. Research in this country continues on at least as high a level in quality and probably higher in quantity as at any time in our history. Major trends in research that have gradually emerged in recent times include the confluence of older fields to produce new and dynamic fields of research, the solution of important problems of ancient vintage, and the increasing importance of algebraic methods in the applications of mathematics.

Finite Group Theory

An important chapter in the development of abstract algebra has seen enormous progress in the past few years. The area under study is the theory of finite groups, and we seem to be witnessing the reaching of a monumental milestone in its evolution.

Group theory was put forward in 1832 by a 20-year-old French mathematician, Evariste Galois, in the 60-page letter to a friend written the night before Galois was shot to death in a duel over a woman. Galois had been concerned with finding a way to solve equations of the fifth or higher powers. Galois found that each solution could be related to one of the members of what he called a "group."

Put formally, a group is a collection of objects (such as numbers) together with an operation (such as addition or multiplication) by which these objects can be combined. For example, the collection of the whole numbers and the operation of addition is a group—in this case an infinite group.

Similarly, the symmetries of a regular polygon such as a triangle and its rotation or flips form a group. In the case of the triangle, it is a finite group of only six elements.

Over the past 40 years a class of examples of finite groups, the "simple finite groups," has attracted some of the best people and the strongest efforts in mathematics. The simple groups are distinguished by the fact that they cannot be collapsed, as other groups can be, into smaller groups. They are the basic building blocks of groups, analogous to the presumed "quarks" that combine to form subatomic particles.

Most finite simple groups fit into one or another of an infinite family of such groups, but there are some that defy such classification. Those working in group theory have believed that there are exactly 26 in this special class, and they have given them the name "finite sporadic groups." If they can prove that there are exactly these 26 sporadic groups, they will have completed, they believe, the classification of the basic groups, thereby creating a firm foundation for further work in other areas that rely on group theory.

At the beginning of 1980, 24 of the sporadic groups were known to exist. This past year has seen the announcement of the construction of what are presumably the last two, of which one, the "Monster," has generated unusual excitement.

The Monster itself is almost inconceivably large, with 808,017,242,794,512,875,886,459,904,961,710,757,005,754,368,000,000,000 members. In fact, the magnitude of this number is such that it is roughly comparable to the mass of the universe—expressed in grams! The construction of the Monster was performed by Robert Griess of the University of Michigan and was partially supported by NSF.

This final step in the program to classify all finite simple groups represents a remarkable achievement but, surprisingly enough, also seems to be the beginning of another chapter. In the process of discovering the Monster, certain startling and still mysterious connections with other, ostensibly unrelated, areas of mathematics were found. These connections are certain to be the major focus of future important research, and exciting results are anticipated.

Hyperbolic Manifolds

In the past few years there has occurred an extraordinary confluence of several large streams of mathematics, e.g., classifical function theory, differential geometry, low-dimensional topology, and several other fields. Many are embodied in the work of William Thurston of Princeton University and are concerned with what are known as hyperbolic manifolds. Historically, the story goes back to the centuries of futile attempts to derive from the other axioms of Euclidean plane geometry the famous fifth (or parallel) postulate, which asserts the existence of one and only one line passing through a given point and failing to meet a given line not containing the given point. These efforts were definitively laid to rest by the construction in the nineteenth century of models of non-Euclidean geometries, in particular Gauss, Bolyai, and Lobachevski's hyperbolic geometry, in which infinitely many distinct lines through a given point fail to meet a given line.

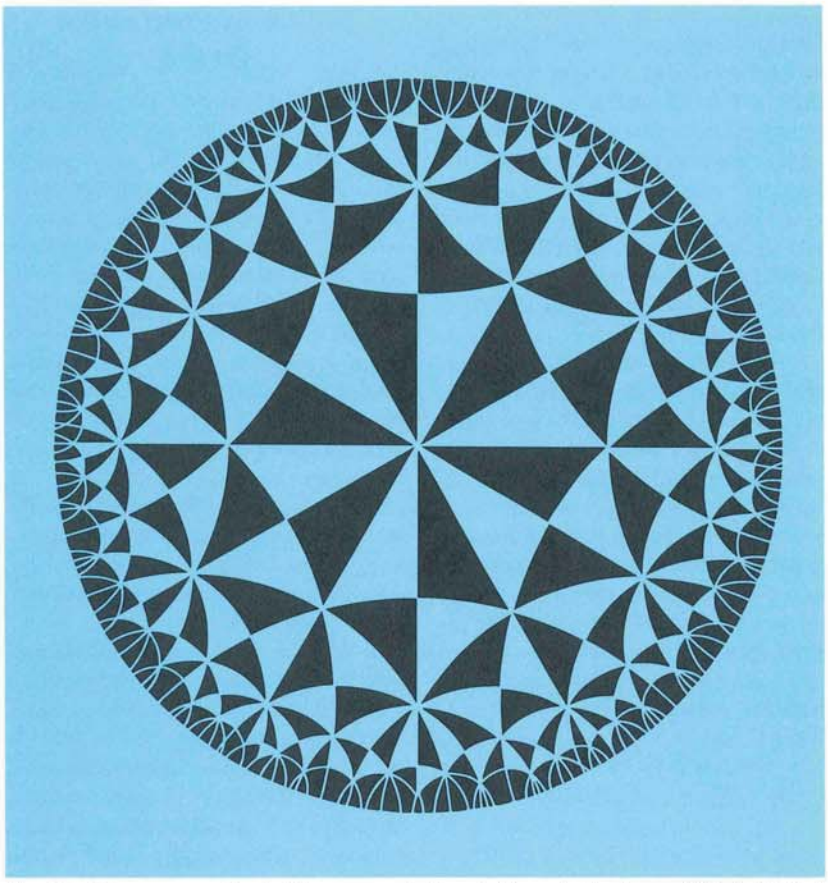
A particularly elegant model of the hyperbolic plane (known as H_2) consists of a circular disk in the ordinary Euclidean plane minus its bounding circle and endowed with a new notion of distance which grows so rapidly along radii that the (missing) boundary points are infinitely far from the center. The hyperbolic straight lines, i.e., shortest paths in the new hyperbolic distance, turn out to be arcs of circles which meet the bounding circle at right angles, from which it is not too hard to see that Euclid's fifth postulate is violated as claimed.

Bizarre as it may appear at first encounter, hyperbolic geometry has a natural role to play in the study of functions of complex numbers (numbers which are the sum of a real part and an imaginary part involving the square root of minus one). Moreover, functions of complex numbers are ubiquitous, arising in such apparently unlikely places as electrical engineering and solutions of equations by integers (whole numbers). The particular, still classical, theorem which advances our tale states the following:

> Theorem A—Most two-sided surfaces (all but the sphere and the torus or doughnut) can be endowed with a notion of distance in which the geometry of any small region is like that of a small region of the model of H_2 described above.

In fact, the study of the great varieties of different ways in which this can be done has given rise to an elaborate theory of the so-called Teichmuller spaces, named after a brillant, fanatical Nazi who died on the Russian front in World War II.

Now just as the Euclidean plane can be extended to Euclidean three-dimensional space, so too can the hyperbolic plane H_2 be extended to a hyperbolic three-dimensional space H_3. Since Theorem A has been exceedingly fruitful in studying surfaces, one might hope for a three-dimensional analog to use in studying three-dimensional manifolds



Non-Euclidean geometry. In this representation of a hyperbolic plane, which is divided into hyperbolically congruent triangles, the shortest paths between points, the hyperbolically straight lines, appear as arcs of circles meeting the boundary circle at right angles (after H.S.M. Coxeter). Hyperbolic geometry is important in a variety of scientific and technological analyses.

(geometric objects in which points have three-dimensional instead of two-dimensional neighborhoods). Only a few examples of hyperbolic 3-manifolds were known until recently, and what is known as the Mostow rigidity theorem discouraged hopes for more by showing that, in striking contrast to the two-dimensional case, a 3-manifold can be given a local hyperbolic structure like H_3 in at most one way.

It is the genius of Thurston to have suspected the existence of many more hyperbolic 3-manifolds, to have constructed large families of new hyperbolic 3-manifolds, and to have derived the right conditions and succeeded in proving by a host of novel methods that these conditions on a 3-manifold ensure that it can be given a hyperbolic structure. The ultimate theorem has probably not been achieved, for his examples go further than his currently best general conditions, suggesting that the methods may yield still more when they are better understood. However, there has already been at least one dramatic breakthrough by use of his results. A notorious 40-year-old conjecture of the late Paul Smith has been settled in the affirmative: A smooth, orientation-preserving, periodic transformation of the 3-sphere cannot have a knotted curve of fixed points. Mathematicians interested in 3-manifolds, in Teichmuller spaces and related matters, in surfaces of minimal area for a fixed boundary, in certain aspects of dynamical systems and ergodic theory, all have been inspired to undertake learning what Thurston has achieved. Some even dare hope that we may be closer to settling the most notorious conjecture in topology, a conjecture the great French mathematician, Henri Poincaré, made at the turn of the century concerning the 3-sphere: specifically, that no other 3-manifold besides the 3-sphere has the same four homology groups and the same fundamental group.

Fluids in Permeable Media

Many fundamental physical processes, from the transfer of heat in a nuclear reactor to the propagation of seismic waves, are appropriately formulated in terms of partial differential equations. Such formulations permit the study of the physical phenomena of interest through the study of the behavior of the solutions of these equations. Very often, such partial differential equations are the basis on which, through the use of a digital computer, numerical simulators are constructed to imitate a phenomenon of interest; with such simulators it is possible to investigate the behavior of the phenomenon under different circumstances in a much more economical and flexible manner than through experimentation, which also is sometimes impossible.

Partial differential equations have been, for a long time, the subject of intensive study not only because of their applicability as appropriate mathematical descriptions of a wide variety of physical phenomena, but because of their inherent beauty as mathematical objects with a complex structure. Their study has also motivated and animated the development of large segments of abstract mathematics, in particular in analysis, functional analysis, and operator theory. The advent of the digital computer has given impetus to the numerical analysis of partial differential equations, the process by which these equations can be approximated digitally within carefully defined bounds of accuracy.

During the very recent past there has been considerable progress in the study of a particular set of partial differential equations and their numerical analysis. These are the equations that mathematically model the flow of multiphase fluids in porous media. The motivation and the ultimate application of such studies is in the simulation of the flows of fluids in rock formations—examples include secondary and tertiary oil recovery by waterflooding; simultaneous production of oil, gas, and water; groundwater exploitation; and chemical leaching of precious minerals. The oil and mineral industry has invested heavily in the development of numerical simulators to study these processes since experimental measurements are extremely expensive, if not impossible.

The partial differential equations that abstractly describe these phenomena are only recently beginning to be thoroughly understood. These equations are nonlinear (mathematically very difficult) and, appropriately, they allow shock solutions—solutions that are discontinuous at the moving interfaces between the several fluids or gases. Theoretical questions of existence, uniqueness, and stability are still being pursued.

There is also great activity in the numerical analysis of these coupled systems of hyperbolic and elliptic equations with the aim of developing approximating methods and appropriate computer codes that, in spite of the discontinuous nature of the solutions, will accurately and within a predetermined level of precision reproduce the physical phenomena. Discontinuous solutions are typical of hyperbolic systems of partial differential equations; shocks appear and are vital not only in multiphase flow theory, but in combustion theory and in aerodynamics.

Discontinuous solutions of hyperbolic equations have generally proved to be very difficult to compute digitally. Most standard techniques, such as finite differences and finite element methods, tend to smear the all-important shock fronts, leading to the phenomenon called numerical diffusion. Moreover, in some cases this smearing leads to qualitatively incorrect solutions. For example, in secondary and tertiary oil production by waterflooding the phenomenon of fingering occurs; as the term im-

plies, the moving boundary between the fluids is not a smooth one, but one in which one fluid intrudes in the other by highly fingered shocks. Most standard numerical techniques tend to obscure this phenomenon, all important from a mathematical and economic viewpoint.

The inherent mathematical importance of the study and numerical analysis of the equations of multiphase flow in porous media have attracted a number of mathematicians whose work not only is intellectually exciting but involves significant cooperation and interaction with applied industrial research organizations.

Among many, a group of researchers led by Jim Douglas and Todd Dupont of the University of Chicago, Bruce Darlow and Mary Wheeler of Rice University, and Richard Kendall of Exxon Production Research Company have actively and successfully pursued modifications of the finite element method for the numerical simulation of such problems. Keith Miller of the University of California, Berkeley, has developed similar methods with adaptive grid changes to preserve the shock structures. James Glimm of Rockefeller University and his associates at the Courant Institute of Mathematical Sciences have developed a novel "random choice method" to compute multidimensional shocks accurately. Interestingly, this numerical method of great promise is an outgrowth of a strictly theoretical technique developed by Glimm to prove existence theorems for hyperbolic partial differential equations.

Computer Science

In its early stages, science dealt with simple situations or with subsystems separated from more complex interactions. Later, systems with more and more information content were introduced; now scientists deal with incredibly complex chemical, biological, and social systems.

Furthermore, these systems are *irreducibly complex* in the sense that their actions cannot be reduced to simple laws. Molecular biology and quantum chemistry are cases in point. Until the advent of the computer there had been a great gap between the handling of simple systems and working with some of the more complex ones that occur in nature. That gap is the region of the irreducibly complex; computer science spans this interval.

Computer science is concerned with algorithms, the constructive definition of a process, rather than the laws governing the behavior of components or of large aggregates. It is a new methodology about which there is much to learn. In fact, the computer system itself is a complicated object, in complexity somewhere between the phenomenological models of the earth sciences and the biological sciences.

Unlike the mathematical sciences, which have a long and rich tradition, computer science is barely 30 years old. It sprang from a remarkable fusion of abstract logic and electronics—the work of mathematicians, logicians, philosophers, and engineers. It has been force-fed by strong commercial demands for service and a revolution in electronics technology that continues to this day. So strong has been the demand for the products and applications of computers, in fact, that it nearly swamped the field; it has been a struggle for the discipline to reassert its scientific origins.

NSF's programs in computer science assume that the science is of fundamental importance and must be fostered, both because of its intrinsic interest and its potential contribution to our future. The research programs in computer science, growing and changing as the community of computer scientists has grown and changed, have consistently emphasized basic research and the application of computers to research. This has not been an easy task; technology and development are much more visible, more commonly appreciated, and easier to describe. Nevertheless, it has been possible to evaluate basic research in computer science and to select a set of programmatic activities that provides scientific balance in the face of the relentless technological and commercial pressures bearing upon the field.

Experimental Computer Science

In recent years academic computer science has moved toward more theoretical studies and away from the experimental research that characterized the early development of machines, operating systems, and languages in campus research laboratories and computer centers. Experimentalists have been moving from academia to industry in large numbers, and academic computer science has witnessed a decline in graduate enrollment and in Ph.D. production. Many persons associate these trends with the poor present academic environment for experimental computer research.

A development that parallels these trends is the changing role of the university computer center. From 1958 to 1972 NSF awarded approximately $80 million to universities and colleges to stimulate the development of academic computing centers. These centers served as tools for research in all fields of science and

engineering, but importantly, the centers were also the focus of experimental research for the newly emerging discipline of computer science. However, as research and instruction in other fields of science came to depend heavily on computers, the university computer center assumed more of a service role. Today we find it no longer able to provide the facilities and staff necessary for experimental computer research. This situation could not have developed at a worse time. The technological impact of microelectronics on computing and communication is creating an intense industrial demand for both new research results and trained scientists at a time when the universities' capacity for reacting to these demands has been seriously eroded.

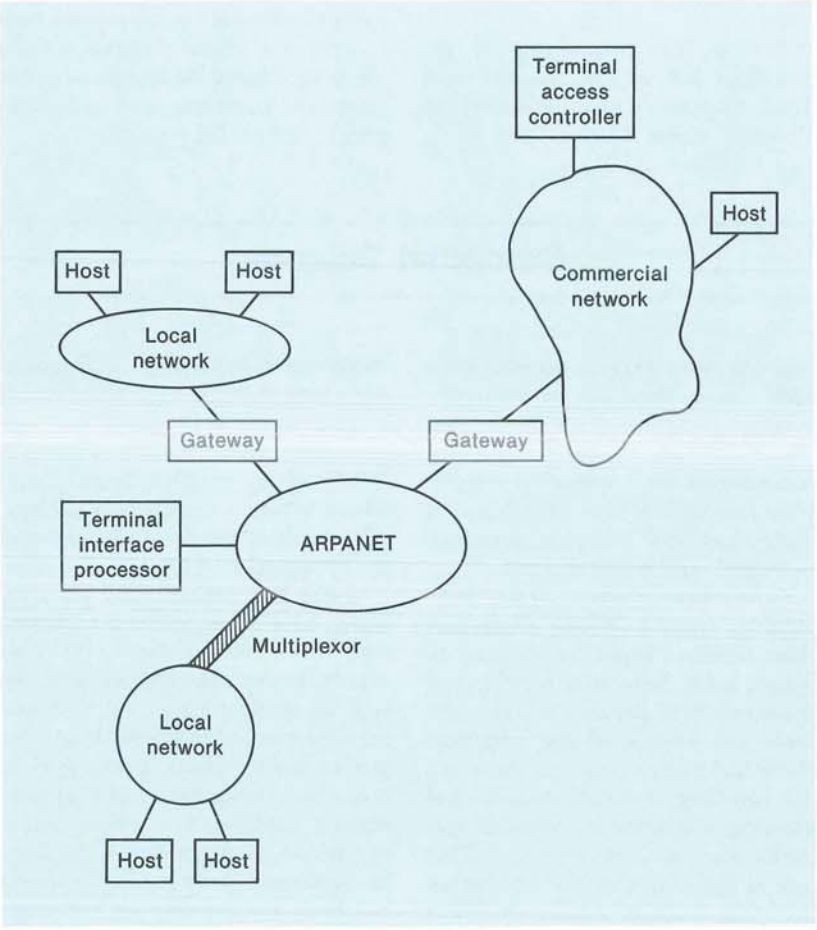
The problems of academic computer science are being addressed in a new NSF emphasis on experimental research. The goal of this program is to provide the critical core support needed to establish viable computer research programs. Emphasis will be placed on stimulating experimental computer science research.

Understanding that each computer science department will have unique problems associated with undertaking an expanded effort in experimental research, NSF has placed no constraints on the kinds of proposals that will be considered by this program. Awards will be of five-year duration (depending on availability of funds) to provide enough time to establish solid research programs. Support levels may be substantial or modest depending on institutional needs. It is expected that support for equipment, technicians, and programmers will be available. Grants may cover single, large projects or multiple projects, perhaps spanning several departments or even campuses.

The first award under this program was made in 1980 to the University of Washington. That five-year, $4.1 million project is concerned with the development and design of a powerful computing environment to facilitate communication and cooperation among researchers in its computer science department. When completed, the facility will be an excellent resource for computer research. Its development will stretch knowledge in a variety of subfields such as computer languages, architecture, operating systems, distributed computation, networking, and personal computing. For this reason, it will be at once both the object of and the tool for a variety of important research projects.

Computer Science Research Network

The pioneering work in network research initiated by the Defense Department's Advanced Research Projects Agency in the 1960's, especially the development of the so-called ARPANET, spurred the growth of



Supernet. Taking advantage of the development in recent years of many different kinds of computer networks to expand research capabilities of individual users, computer scientists have begun a grand interconnection of many U.S.-based systems. The project, scheduled for completion in five years, should lead to increased productivity in public and private sector research.

numerous private and public computer networks throughout the world. One result of these early efforts is that in the United States today these networks are rapidly becoming an integral part of scientific research projects involving computer-aided modeling, analysis, and design.

Computer networks are of several types. One places all network activity under the control of a centralized computer connected directly to all users. In another configuration, called the homogeneous network, two or more interconnected, similar computers run the same operating system. Such compatibility permits easy interface between the user and the host and facilitates load sharing.

The most versatile type of network system is heterogeneous in character. It makes a range of services available through geographically dispersed computer systems, called hosts, which may have different operating systems, accounting algorithms, architectures, and programming languages. Although the connection of host to the network requires significant effort, a distributive system provides many advantages, including the sharing of locally available software and hardware, data bases, and research personnel. Remote scientific collaboration is also enhanced through file transfers, device-independent graphics, interprocess communications, and network mail facilities.

The use of network mail facilities is already widespread. The impediments to communication posed by differing work schedules and time zones, conventional mail delivery delays, and the high costs of long distance telephone calls are all avoided. When used with editing and document-preparation systems, network mail systems also can facilitate the preparation and dissemination of research results.

Experience so far suggests that there is an immense payoff to improving meaningful collaboration among research teams. NSF, as a step toward upgrading computer science research equipment throughout the country, is now in the process of helping connect existing networks to form a logical supernet, called Computer Science Network (CSNET).

The underlying assumption of CSNET is that no single network is completely adequate for all hosts and users. Therefore, a multiple network environment must be created to accommodate extreme requirements, from stand-alone hosts to very rapid interprocess communication among several hosts, all at the same time and independently of local network traffic.

A team led by researchers at the Universities of Wisconsin and Washington has been investigating ways to achieve these objectives. The principal means of interconnection between nets is a "datagram" gateway, which accepts internet packages, or packets, of information. These packets incorporate an internet identifier, or header, wrapped in the local packet format. The gateway examines the internet header and re-wraps the packet for forwarding to the next network. This internet architecture is being planned to operate between many different U.S.-based network systems (e.g., ARPANET and commercial networks, with the possibility of expansion to Canadian and European nets).

It is anticipated that CSNET will require five years to develop, at which time it will become self-sustaining. Once completed, it should increase the productivity of scientists at universities, industries, and government laboratories and help develop unity among computer scientists throughout the Nation. It will also serve as a model for other disciplines.

Materials Research

The diverse materials research activities supported by NSF share a common goal to understand the behavior and properties of materials in terms of (1) microscopic interactions between their fundamental constituents and (2) their bulk- and microchemical composition and structure.

Support for the materials-related areas of metallurgy, ceramics, polymers, solid state physics, solid state chemistry, and low temperature physics is geared toward both theoretical and experimental disciplinary research. In addition, through its materials research laboratories program, NSF encourages strong interdisciplinary approaches as well.

The past year witnessed major advances on many fronts. Synchrotron radiation facilities expansions at Stanford, Wisconsin, and Cornell were either completed or nearly completed in 1980. The Small-Angle Neutron Scattering facility at Oak Ridge National Laboratory became operational early in 1980. These national user facilities provide sophisticated experimental capabilities critical to forefront research, not only in materials research, but in chemistry, physics, engineering, and the biological sciences as well.

One of the more interesting and exciting research areas involves the study of systems of reduced dimensionality. In the past, most materials research dealt with the bulk (i.e., volume) properties of matter. It is now possible to prepare and study specimens whose dimensions in one or two directions are so small (e.g., monomolecular layers) that the normal properties and phenomena of

the bulk no longer obtain. The consequences for conductivity of reducing the diameter of a metal wire (making it essentially one-dimensional) are further described later in this section.

Considerable interest has been focused on two-dimensional systems, which have had a traditional role in physics of providing solvable models from which three-dimensional behavior might be inferred. These systems are now of interest in their own right, and a new phenomenology is developing that affects surface and interfacial physics, chemistry, and metallurgy.

The melting of thin films is a case in point. According to the recent theory of Bertrand Halperin and David Nelson of Harvard University, two-dimensional melting requires two distinct phase transitions. First, dislocations unbind at a certain temperature into a phase with no long-range translational order, but with persistent correlations in the orientations of bond angles. Paired disclinations (which are defects in which an atom does not have the normal number of neighbors) in this phase ultimately separate at a higher temperature, resulting in a second transition to an isotropic liquid.

The theory is applicable to a wide variety of experimental systems, such as adsorbed monolayers, electrons on a helium surface, and liquid crystal films. A recent experiment by David Moncton and Ronald Pindak of Bell Laboratories and George Brown of the Stanford Synchrotron Radiation Laboratory shows evidence of the postulated intermediate phase in thin liquid crystal films. In addition, Robert Birgeneau of the Massachusetts Institute of Technology has developed a technique (also using synchrotron radiation) to measure the decay of positional coherence during these phase changes. Peder Estrup of Brown University has observed surface reconstruction on single crystal surfaces of tungsten and molybdenum using low energy electron diffraction. These structures undergo order-disorder transitions analogous to monolayers.

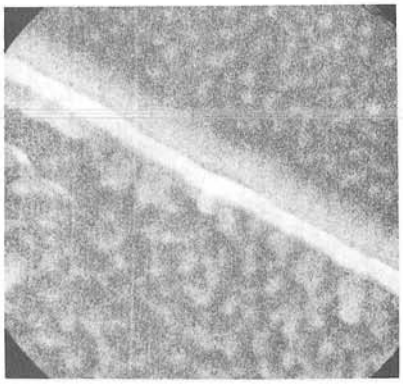
At Northwestern University, John Hilliard and John Ketterson are exploring the properties of materials called compositionally modulated alloys. A thin film, consisting of two elements such as copper and nickel, is vapor-deposited so that the composition varies in a continuously modulated manner across the thickness of the film. The "wavelength" of the modulation is typically 2 to 5 nanometers, or 20 to 50 atoms. Such films have unusual mechanical and magnetic properties. Both the elastic modulus and magnetization of the modulated structures are appreciably greater than those of either element. A possible explanation for the enhanced magnetization is that the modulation alters the spacing between atoms and, in turn, the electron interactions. These initial observations suggest a number of interesting technological possibilities, such as improved superconductors, membranes with a high modulus of stiffness, or bulk materials with enhanced elastic moduli or corrosion resistance.

The inferences to be drawn from these and other recent developments are far-ranging and suggest that prior theories of reactivity, crystal growth, alloying, and defect dynamics involving surfaces or interfaces that did not allow for the two-dimensional thermodynamic behavior of the interface *per se* will require major modification.

When is a Metal not a Conductor?

An ordinary metal, such as copper or gold, is a good conductor of electricity. In addition, as the temperature of the metal is lowered, it becomes a better conductor; the resistance of a piece of metal decreases as the temperature is decreased, and it approaches a finite value as one approaches the lowest temperature attainable. However, there is increasing evidence that this typical "metallic" behavior does not occur when the sample is made into the form of a very long, very thin wire—here "thin" refers to the diameter of the wire. David Thouless of Yale University and now at the University of Washington has presented theoretical arguments to show that at low temperatures the resistance of a thin wire should increase and not decrease at the lowest temperatures. Thus, a very thin wire would be an insulator as opposed to a "large" sample of a metal, which will be a conductor at zero temperature. This peculiar behavior of thin wire is caused by a basic physical phenomenon called localization.

Nicholas Giordano and his collaborators at Purdue University have conducted experiments aimed at observing the effects of localization in thin wires. These experiments are difficult because the temperature at



Limits of conductivity. Recent experiments confirm the surprising theoretical prediction that very thin metal wires—only 350 angstroms thick in this sample—are very poor conductors of electricity, even at low temperatures where larger wires of the same metal are superconducting. This micro-effect may become critical in the continued miniaturization of electronic circuitry.

which the effects are observable requires that the wires must have diameters of less than a thousand atom spacings. Making wires this small is a major experimental problem, but has been overcome by using a shadowing technique. A glass microscope slide, half-covered with a metal film, is bombarded perpendicularly with a beam of argon ions, which "mills" a ridge into the surface. The metal film is then removed chemically, leaving a step in the glass. A second metal film is next deposited, and the surface is then milled again with the ion beam, but this time at an angle such that the metal on the side of the step is in the "shadow" and is thus protected. The result is a wire that runs along the step. A gold/palladium wire made in this way is only 100 atoms across.

Giordano has measured the resistance of these wires at different temperatures and diameters. His results are in qualitative accord with the predictions of Thouless: The resistance of a wire increases as the temperature is lowered, and this resistance rise increases as the diameter of the wire decreases. He notes too that the resistance of thin films also increases as the temperature is lowered. This appears to be due to the effects of localization in two-dimensional systems, which confirms earlier results obtained at Bell Laboratories on thin films. While the results for the thin wires are in good qualitative agreement with the theoretical predictions, the actual magnitude of the resistance rise and its temperature dependence do not agree with the original theoretical estimates of Thouless. Very recently, some new theoretical ideas have been proposed, and the latest predictions are in better agreement with the experimental results.

These results for very thin metal wires and their films are quite startling. Metallic behavior and electrical conductivity in bulk metals have always been assumed to be synonymous. The use of metals in the electrical and electronic technologies depend on this conductivity. The discrepancy has not been a problem to date because the dimensions for wires and films presently available to technology are gross on the scale of atomic dimensions; they behave like "real" metals. However, as dimensions shrink and tolerances become more restrictive, the effects of dimensional constraints in microstructures will become increasingly important.

Polymeric Ionic Conductors

In the search for more effective energy storage systems, renewed attention has been focused on storage batteries with high efficiency, power density, reliability, and stability. To have all these attributes, it would seem that a cell should be based on a solid, rather than liquid, electrolyte. Most of the past work on solid electrolytes has been devoted to ceramic materials, which are stable and long-lived. They have several disadvantages, however, including very high operating temperatures and brittleness.

Brian Papke, a graduate student working in the Materials Research Center at Northwestern University, has recently been exploring a different type of solid electrolyte, one based on a polymer. Polymers have several advantages, including light weight, ease of fabrication, low cost, and good thermal stability. The major difficulty is that they are generally very poor conductors, rendering them useless as electrolytes. Papke's work was stimulated by the results of a French study which showed that poly(ethylene oxide) can be made into an ionic conductor (electrolyte) if it is combined with alkali metal salts such as sodium thiocyanate. Papke has prepared a number of salt-complexed poly(ethylene oxide) materials and has characterized them by their conductivities and thermal properties.

One unusual feature of Papke's work has been the preparation of thin-film polymeric electrolytes. For cell applications, this is a considerable advantage, since the overall resistance can be lowered either by raising the conductivity or by reducing the distances over which current must flow. Papke's films are clear, thin, stable, conductive, and formable. In collaboration with four Northwestern faculty members (Duward Shriver, Mark Ratner, Donald Whitmore, and Morris Brodwin), Papke has investigated the structures of poly(ethylene oxide) salt complexes to understand the origin of fast ion transport in polymers. His structural model for the ion-containing polymer indicates considerable rearrangement from the native poly(ethylene oxide) conformation.

These structural results imply a conduction mechanism in which the ions migrate along the helical polymer by a series of random jumps that are directed by the electrode potential difference in the cell. These jumps can be facilitated by raising the temperature, but the films perform satisfactorily even at room temperature (in contrast to ceramic conductors, whose applications are limited to high-temperature batteries). Spectroscopic and conductivity studies also show that the mobile ion can be trapped by ion pair formation. However, various strategies are now being pursued to enhance the mobility of the ion by minimizing this trapping mechanism.

The structural information also suggests that flexible polymer hosts are desirable because they can rearrange to accommodate mobile ions. This premise is being used to guide the synthesis of new ion-containing materials based on different polymers and with various alkali salts, in an attempt both to increase the conductivity and to understand what processes (trapping, collective hops,

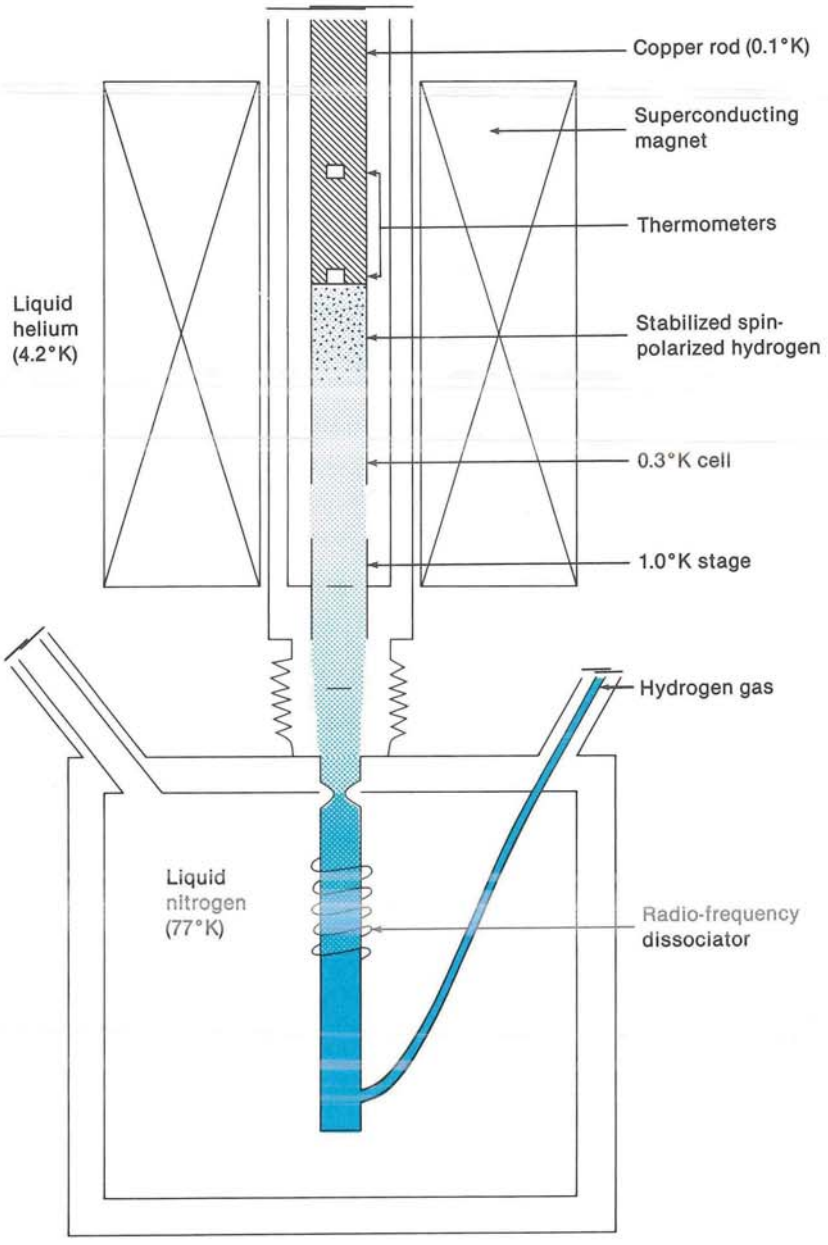
chain wriggling) can lead to differing temperature-dependent and density-dependent features in the conduction.

Spin-Polarized Atomic Hydrogen—A New State of Matter?

Until recently it was generally believed that all matter condenses as the temperature is reduced. With the exception of helium, the condensed state is ultimately a solid (helium forms a liquid at 4.2K, but resists solidification under its own vapor pressure down to absolute zero). Now, however, it is predicted that some systems will remain gaseous at arbitrarily low temperatures. As the temperature is reduced these systems will condense into a new state of matter, a quantum gas displaying such unique phenomena as Bose-Einstein condensation and gaseous superfluidity.

Studies to date center around one system—spin-polarized hydrogen (H↑)—a gas of hydrogen atoms in which the electron spins are all parallel. Interest in H↑ is technological as well as scientific. A system of H↑ has the highest chemical energy storage per unit mass of any known substance. As a rocket fuel H↑ would have a specific impulse four times that of liquid hydrogen and oxygen. At the moment, practical applications for H↑ are still distant.

From a fundamental point of view, the experimental observation of Bose-Einstein condensation in a gaseous fluid would open research into an entirely new state of matter and offer the opportunity to study some of the most interesting many-body effects in a simple and well characterized medium. Static and dynamic critical phenomena, finite occupation of a single quantum state, long-range order, and the density dependence of the collective interaction could all be studied in a gas of H↑.



New state of matter? Using devices such as this, scientists have produced a gas of atomic hydrogen in which all electron spins are parallel. This gas, which has the highest chemical energy content of any known substance, is also ideally suited for the study of the phenomenon of superfluidity. The equipment introduces molecular hydrogen gas to the system, cools it to 77°K, then dissociates it into atomic hydrogen by a radio frequency discharge. Intense cooling in a strong magnetic field produces the unique gas, which can be maintained for more than an hour.

To observe the predicted Bose-Einstein condensation in spin-polarized atomic hydrogen, one needs to obtain a stable, spin-polarized gas

with a density of about 10^{19} atoms per cubic centimeter and cool it to below 0.2K. The availability now of successfully interfaced superconducting solenoids and dilution refrigerators of sufficient cooling power may finally make possible realistic search for a Bose-Einstein condensation in H↑. Thomas Greytak, Daniel Kleppner, and colleagues at the Massachusetts Institute of Technology were able to stabilize four cubic centimeters of H↑ at a density of 10^{17} atoms per cubic centimeter for longer than one hour at a temperature of 0.1K. The key to achieving this rather long lifetime was the use of a film of superfluid helium to coat the inside wall of a sample chamber, thereby preventing recombination of the hydrogen atoms at the walls.

Thus it appears that we are on the verge of being able to unambiguously test theories of Bose-Einstein condensation and its relation to the occurrence of superfluidity. Another research group at Cornell University headed by David Lee and Jack Freed is pursuing similar studies.

Metallic Glasses

In the late 1950's, when Pol Duwez and his students at the California Institute of Technology first developed the "splat-cooling" technique for ultra-rapid solidification of molten metal, they were primarily interested in a basic understanding of maximum solid solubilities of metallic alloys. Their original objective is now of minor importance compared to the new industry which is being spawned as a result of their efforts. When certain molten alloys are quenched at a rate of 100,000 to 1,000,000°C/sec, there is inadequate time for crystallization, and an amorphous (noncrystalline) solid is formed. Important glass formers currently consist of transition metals and metalloids such as carbon and boron.

These Duwez glasses are unusual in a number of important aspects. They are metallic, and at several compositions have ferromagnetic characteristics. Several alloys of chromium-iron-boron are far more corrosion-resistant to attack from sea water than commercial stainless steels with similar compositions. Iron-boron metallic glasses have yield strengths much in excess of those for commercial steels. The major advantages ferromagnetic glasses have over existing crystalline magnetic materials are very low coercive forces coupled with high values for saturation magnetization. Such alloys are being studied for use in high-performance/low-energy-consumption transformers.

Many corporations are actively developing these materials for commercialization. Because so many metallic glasses have useful properties, the search for new glass formers is intense. At Northeastern University, William Giessen and his colleagues have discovered that alloys containing calcium are excellent glass formers. Alloys of calcium-aluminum have unusually high electrical resistivities for metallic glasses, approaching those typical for electron transport via a hopping mechanism. Giessen is developing correlations between the properties of the glass formers and those of the underlying crystalline materials so that a more systematic search can be conducted for new glass formers. Metallic glass formers consisting of light elements such as calcium and aluminum are particularly interesting because of their potential as high-strength/low-weight structural materials. Use of these alloys in aircraft, for example, could substantially improve energy efficiency or performance.

At MIT, Ronald Latanision and his colleagues are studying the corrosive behavior of metallic glasses. One explanation for the observed superior corrosion resistance is that these materials have no grain boundaries to allow rapid transport of corrosive constituents to the material's interior. Also, their homogeneous compositions preclude galvanic cell formation.

Latanision finds, however, that certain metallic glasses, such as copper-zirconium, do not have significantly improved corrosion resistance over devitrified alloys of the same composition. There is selective anodic dissolution of zirconium and hydrogen generation at the cathodic copper. Iron-based metallic glasses, although more corrosion resistant, are subject to hydrogen embrittlement. These glasses absorb considerable quantities of hydrogen during electrolytic charging experiments and then fracture catastrophically. Cracking initiates at traps for molecular hydrogen, such as at microvoids. One possible explanation for the improved corrosion resistance in other environments is that the smoother glasslike surfaces, compared to rougher crystalline surfaces, reduce the exchange currents needed for cathodic evolution of hydrogen.

In summary, the useful properties of metallic glasses are rapidly being exploited by industrial developments. Many fundamental aspects of these materials remain a mystery and could limit applications, but the potential for these materials is enormous. It is conceivable that the metallic glasses with broad-range, useful properties will have at least as great an impact on modern society as did the advent of semiconductors.

Astronomical, Atmospheric, Earth, and Ocean Sciences

2

Astronomical, Atmospheric, Earth, and Ocean Sciences (AAEO) programs are the prime focus for geophysical sciences within NSF. These research programs ascertain the how, when, where, and why of terrestrial and extraterrestrial events whose consequences have a bearing on the quality of life on Earth. Subjects range from the microphysics of cloud droplet processes to the macroscale of intergalactic relationships; the time scales involved vary from microseconds to eons and the distances from a fraction of a millimeter to millions of light years. The form of support for this research ranges, also, from grants to universities for individual investigators, to grants to groups of such individuals working together on a major project, to the support of national research centers and facilities.

NSF is the predominant source of support for ground-based astronomy in the United States. Research grants are made to more than 140 universities, private observatories, industrial firms, and Federally owned observatories. In addition, NSF funds the development, operation, and use by staff, visiting scientists, and graduate students of advanced observing facilities at the National Astronomy Centers. The newest of these facilities, the Very Large Array (VLA) radio telescope and its 27 antennas along a wye-shaped track in Socorro, New Mexico, is now complete. The VLA provides high-resolution radio-frequency observations of a variety of celestial objects.

Astronomical studies are continuing of the recently discovered multiple quasars, of the unique stellar object SS 433, and of violent events in other galaxies. These observations are made across a broad spectrum of wavelengths, ranging from the radio and infrared through the optical and into the ultraviolet and X-ray regions, with highly advanced instruments and data-handling techniques. At the same time, NSF also supports theoretical studies of the phenomena that are being observed.

Atmospheric sciences, through its project support programs and through the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, and the National Scientific Balloon Facility (NSBF) in Palestine, Texas, funds basic research in aeronomy, atmospheric chemistry, climate dynamics, meteorology, weather modification, and solar terrestrial research. NCAR and NSBF are operated by a consortium of 47 U.S. and 2 Canadian universities. Important results in 1980 in-

Table 2*
Astronomical, Atmospheric, Earth, and Ocean Sciences**
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Astronomy	227	$15.65	248	$16.34	244	$17.66
Atmospheric Sciences	434	29.74	475	31.98	433	34.48
Earth Sciences	442	34.07	503	24.92	491	25.48
Ocean Drilling	***	***	0	11.62	0	19.47
Ocean Sciences	655	58.18	662	62.39	624	66.31
U.S. Antarctic Research	132	48.45	140	51.09	126	55.84
Arctic Research	78	5.34	87	5.97	67	5.82
Total	**1,968**	**191.43**	**2,115**	**204.31**	**1,985**	**225.06**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

** Excludes National Research Centers (See Table 3)

*** Included under Earth Sciences.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

clude the Global Atmospheric Research Program's Monsoon Experiment, which completed its scientific field studies with significant research results. A number of studies have been completed relating to the effect on climate of the predicted increase in worldwide atmospheric carbon dioxide. The recent eruptions of Mount St. Helens in southern Washington afforded new opportunities for research on the possible effects of volcanoes on climate and weather. NSF participated with NASA in support for observational activity during the peak in solar activity that occurred in 1980.

Propelled by two decades of revolutionary ideas and discoveries, the earth sciences entered the 1980's advancing rapidly along many fronts. The importance of earth science research, dramatized by the explosive eruptions of Mount St. Helens, was intensified by growing concern over natural resources, geologic hazards, and solid waste disposal. Major achievements in 1980 included discoveries about mantle composition and dynamic behavior, deep continental structure, and trace element distributions in the sedimentary record.

On October 1, 1980, the ocean sediment coring program, which for many years had been a part of NSF's programs in earth sciences, became an independent unit designated the ocean drilling programs (ODP). ODP consists of the deep sea drilling project (DSDP) and the ocean margin drilling project (OMDP). OMDP will begin a major cooperative effort between universities, private industry, and the U.S. Government in 1981 under a 50/50 cost-sharing agreement between the Government and the oil industry for the initial phase of the project. This initial phase is a scientific and engineering design effort, at the conclusion of which will be the major go/no-go decision point.

A major discovery during 1980, attributed in part to operations of the on-going deep-sea drilling project aboard the D/V *Glomar Challenger,* involves the mysterious extinction of the bulk of the surface-dwelling life forms in the world's oceans some 65 million years ago. This was synchronous with the equally mysterious extinction of the dinosaurs. It has been hypothesized that this event may have been caused by the impact on the Earth's surface of a large asteroid; such a collision could have created a large dust cloud that decreased photosynthesis enough to affect all life on Earth.

Activities supported in ocean sciences improve the understanding of the nature of the ocean, its influence on human activities, and, conversely, society's impact on the marine environment. These studies are addressed through oceanographic research grants in biology, chemistry, geology and geophysics, and physical oceanography. NSF supports the operation and maintenance of the oceanographic facilities needed to conduct that research. Two new coastal zone research vessels were under construction by June 1980 and should begin research operations in late 1981. These ships, modern and cost-effective, will allow scientists year-round opportunities for oceanographic research.

Scientists on the research submersible *Alvin* have discovered hydrothermal vents that account for very large heat fluxes in the deep ocean and may provide a model for how mineral deposits are formed. The vents are also characterized by a unique biological ecosystem whose source of energy is derived from chemical reactions other than sunlight-driven photosynthesis.

NSF is one of several sources of Federal funding for research in the Arctic and is solely responsible for the funding and management of the U.S. program in the Antarctic. Research and maintenance of facilities and logistics for it provide a U.S. presence in Antarctica. Because of fuel price increases and increases in the charter cost of aircraft and ships, it was necessary in 1980 to reduce funding for both research and some support components of the program. However, a number of notable accomplishments occurred this year, including a major geological and glaciological investigation of Antarctica's Ellsworth Mountains, a heretofore little-known area of that continent. In the Arctic a 901-meter core was recovered from the Green-

Table 3*
National Research Centers
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978	FY 1979	FY 1980
	Amount	Amount	Amount
Kitt Peak National Observatory	$9.13	$9.70	$10.50
Cerro Tololo Inter-American Observatory	3.88	4.35	4.83
National Radio Astronomy Observatory	22.15	22.70	17.03
National Astronomy and Ionosphere Center	5.48	4.63	4.99
Sacramento Peak Observatory	1.29	1.50	1.66
National Center for Atmospheric Research	24.90	25.26	26.59
National Scientific Balloon Facility	1.77	1.87	2.20
Total	**68.60**	**70.01**	**67.80**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

land Ice Sheet for reconstruction of paleoclimate, and the third season of work on the structure and functions of the marine ecosystem on the continental shelf of the southeastern Bering Sea was completed.

Astronomy

Astronomy continues to change rapidly and profoundly. The pace of new discoveries persists unabated and makes it, the oldest of all sciences, one of today's most intellectually stimulating and rewarding fields. New observational techniques exist at many wavelengths, and the modern astronomer can now study most celestial objects at X-ray, ultraviolet, optical, infrared, or radio wavelengths. The progress in astronomical instrumentation that has made this possible has gone hand in hand with advances in our understanding of the fundamental problems of astronomy. Astronomers increasingly deal with questions involving the very structure of the universe, its origin, and its ultimate future.

Our galaxy is only one among countless similar galaxies observed to the farthest distances radio and optical telescopes penetrate. It exists in a universe filled with such bizarre objects as quasars, pulsars, black holes, and neutron stars—as well as with ordinary stars, gas, and dust. Numerous types of organic molecules exist in the depths of interstellar space. The cataclysmic death of a star in the form of a supernova can lead to the birth of new stars. And space is filled with radiation that dates back to the very origin of the universe itself. Seemingly inexplicably violent events are observed in the regions within and surrounding many galaxies. Observations of a binary pulsar indicate the existence of gravitational radiation. Double and triple quasars make it appear likely that gravitational lenses exist in space. Strange sources of X-ray radiation are observed in the depths of globular clusters. Cosmic rays with extraordinarily high energies are detected, but their origin remains a mystery. New types of stellar objects are discovered, but satisfactory explanations are still lacking as to what they might be. These are only a few of the many topics in astronomy that indicate its scientific frontiers and make it a field that continues to attract the broad interest of the general public.

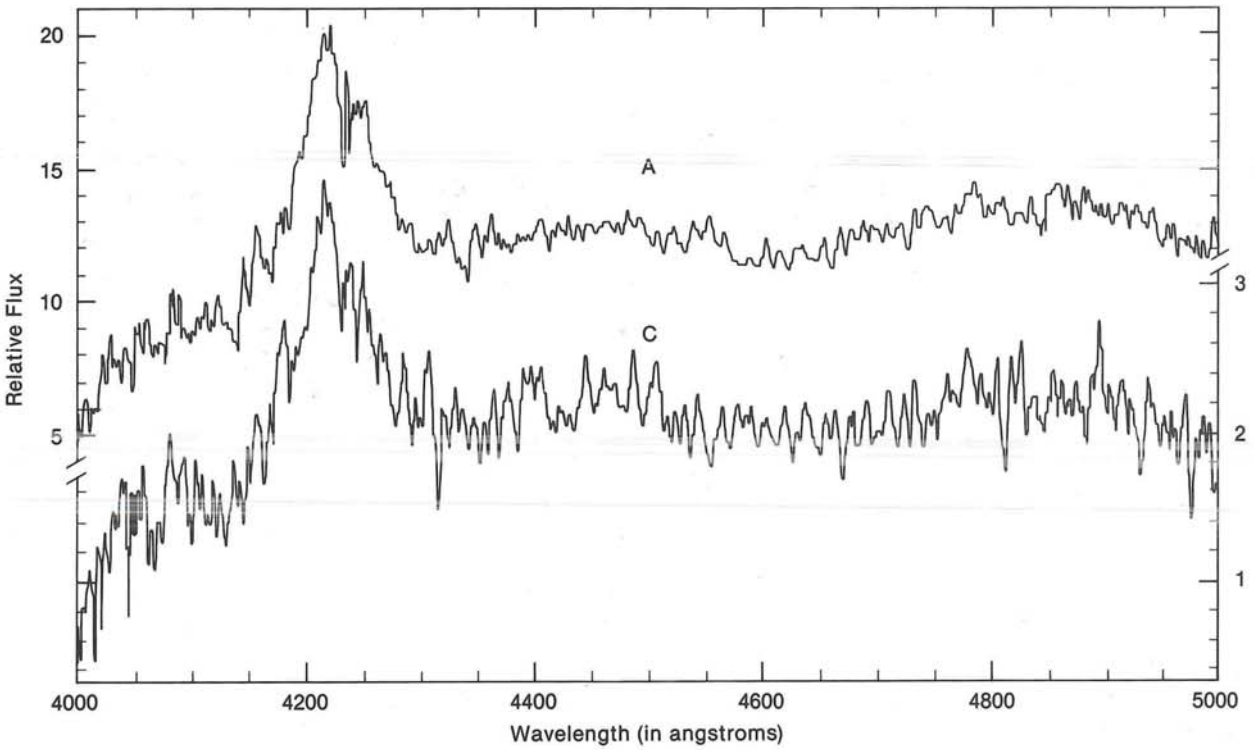
NSF funds research into these and many other areas of astronomy at more than 140 universities, private observatories, industrial firms, and federally owned observatories. Support comes in the form of research grants and allotments of observing time at national or regional observatories. Ground-based and theoretical studies of the solar system, the Sun, stars, the motion of stars, the composition and evolution of stars, the composition and structure of the interstellar medium, and the structure of this and other galaxies, clusters of galaxies, and intergalactic space are all supported by NSF. In addition, there is an active program to develop new instrumentation and computational capabilities.

Astronomers who do not have adequate observational facilities at their own institutions have access to five National Astronomy Centers supported by NSF: the National Astronomy and Ionosphere Center, Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, the National Radio Astronomy Observatory, and Sacramento Peak Observatory. These centers are a national resource available to astronomers at universities, industrial organizations, and other Federal laboratories. The centers' telescopes, instruments, and facilities are among the most advanced in the world for investigations in radio, millimeter, infrared, optical, and solar astronomy. The staff at these observatories, in addition to providing assistance to visiting astronomers, also maintain active research activities of their own.

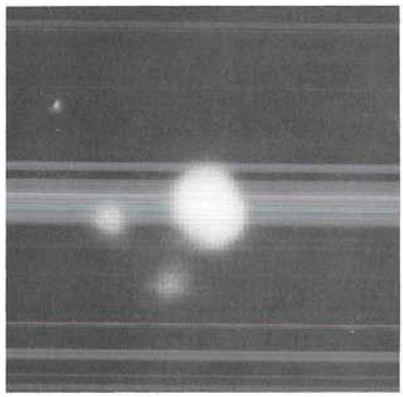
Multiple Quasars

Since the discovery of the law of gravitation by Isaac Newton, much of the behavior of a mass under the influence of gravity has been well understood. Einstein's later insight predicted that a particle of "pure energy" (i.e., light) should also be influenced by gravity—in this case, deflected by the gravitational field of a massive object. One of the key tests of general relativity, in fact, is to compare Einstein's precise prediction of the amount of this deflection (as starlight passes near the sun, for example) with the measured amount, a test which is still occupying the attention of experimental physicists.

There is a fascinating consequence of the deflection of light, which was appreciated and investigated by Einstein and by many others. Under ordinary circumstances, light travels in a straight line. However, if there is an intervening massive object at some point along the light path to deflect the beam, then it is possible for the light to take several distinct alternate routes (each being deflected by differing amounts). From the observer's point of view, the beams of light appear to be coming from slightly different directions and therefore give the illusion of several distinct light sources. A slight focusing effect of the deflector will also tend to make some of the images abnormally



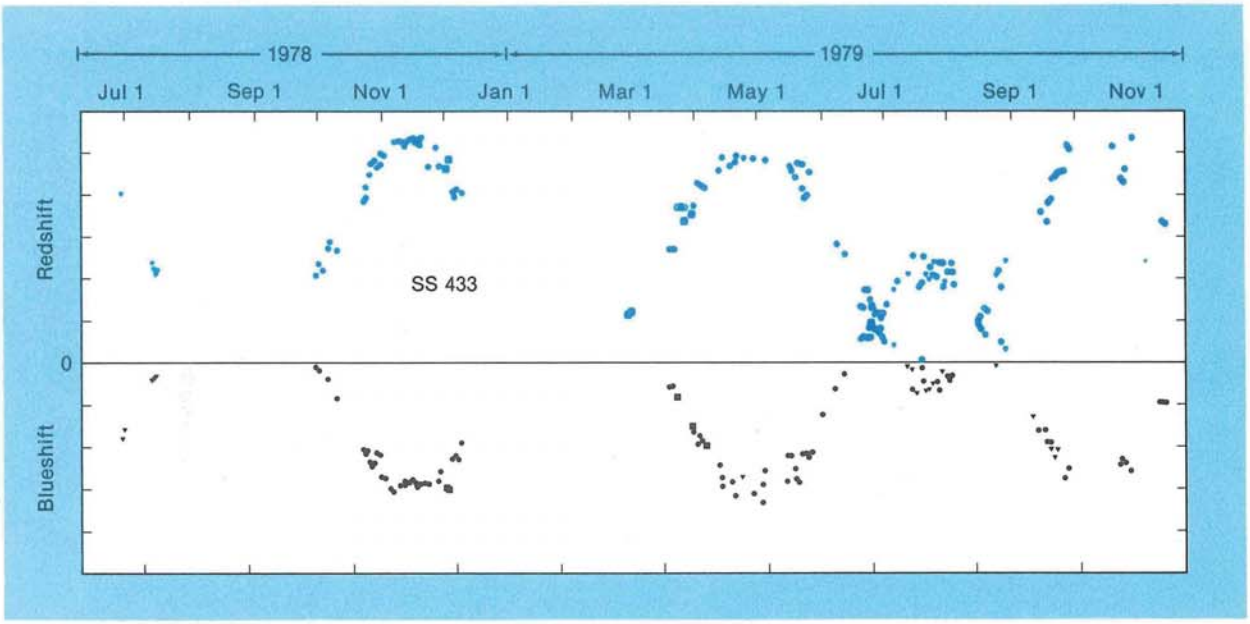
Triple quasar or triple image? Although appearing to be three objects in this photograph, these quasars are probably one, with the two faint images being produced by a gravitational lens in space. A spectrum of the bright central object (tracing A) is virtually identical to that of either apparent companion (companion B is shown)—highly unlikely for truly separate objects. This phenomenon, predicted from the general theory of relativity, has only been confirmed in the past two years.



bright; this phenomenon has come to be known as a "gravitational lens."

Quasars are starlike objects of tremendous luminosity and distance, believed to be centers of violent activity in the nuclei of galaxies. Their starlike appearance and vast distance make them the most likely objects in which a gravitational lens effect might be seen. In the spring of 1979 (as described in NSF's *Annual Report* for 1979) two British astronomers, Dennis Walsh and Robert Carswell, and an American, Ray Weymann, discovered a close optical pair of quasars whose properties were so identical that it appeared to them inescapable that the images were produced by the same light source. Subsequent observations seemed to confirm that these twin quasars do indeed represent a gravitational lens in action.

The theory has been further advanced in the past year. In March 1980 Weymann, along with David Turnshek and Richard Green, was carrying out a study of the spectral properties of a set of quasars. While viewing the image of one of the quasars prior to recording its spectrum, Turnshek and Weymann noticed that the image actually consisted of a bright image and two very close but much fainter images. Since the likelihood of two ordinary stars appearing by chance so close to the bright image is small, they realized that the two fainter images were likely to be of considerable interest. Further observations were carried out at the Multiple Mirror Telescope, a joint project of the University of Arizona and the Smithsonian Institution. The critical and difficult observation was to obtain a spectrum of one of the faint companion images: If a gravitational lens were operating, the spectra of the images should be identical, since the same source of light is responsible. In fact, the spectra they recorded appear identical, within the accuracy of the observation, thus lending strong



Mysterious beacon. Measurements of shifts in wavelength of light—which are considered to indicate velocity relative to the Earth—show astounding, opposite fluctuations over time for the object SS 433. SS 433 may be rotating as it emits opposing beams of gas at very high speed, but the mechanism involved is unknown. This is the only star with this behavior ever observed by astronomers.

support to the existence of another gravitational lens—in this case producing a triple image.

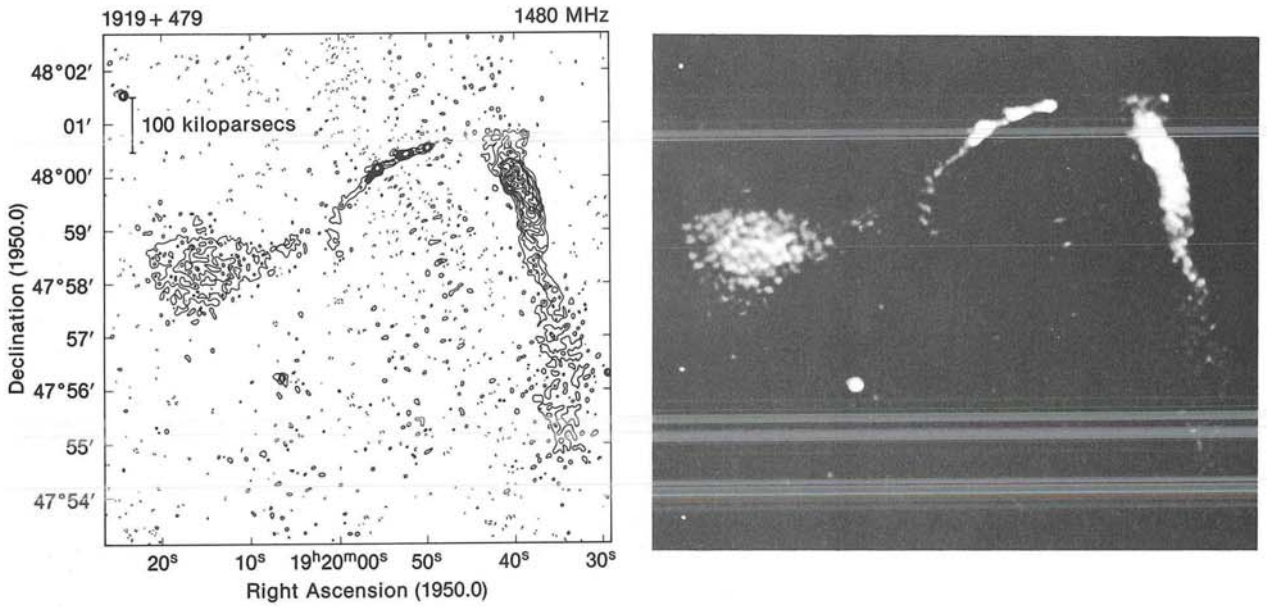
The Peculiar Star SS 433

Although there are many objects with strange properties in the universe, it is usually possible to classify them in some manner. This has not been the case with the peculiar star known as SS 433, located in the constellation Aquila. The star was first discovered optically more than 15 years ago, but in 1978 three groups noted independently that it coincided with a region of strong and variable radio and X-ray emission. The position of SS 433 was almost exactly in the center of a prominent diffuse radio source known as W50. This radio source was thought to be the remains of a supernova, and it was originally thought that SS 433 and W50 were physically related.

However, a study of the visible light spectrum from this object had more surprises in store. It was found that the spectrum contained several strong, broad emission lines at wavelengths that did not coincide with any of the common chemical elements which can usually be identified in astronomical spectra. It was also found that these lines varied in wavelength by a significant amount on a time scale of 24 hours.

Usually such variations in wavelength result from a Doppler effect—changes in relative motion between a wave source and the observer. If so, the measured velocities and changes observed in SS 433 were greater (by a factor of 100) than anything that had been observed in any other stellar object. Of even more interest is that pairs of lines are seen, one displaced toward shorter, the other toward longer wavelengths. This would imply that there must be some gas moving toward the observer while there are other parts of the gas that are moving away from the observer. In both cases the velocities are very high, and measurements have now been made that show that these emission lines originate in a gas moving at a velocity exceeding one-quarter the speed of light.

The question remains as to what this peculiar object really is. Bruce Margon of the University of California, Los Angeles (who is now at the University of Washington), found that the moving emission lines cycle through a repeating pattern every 164 days. This change has been interpreted as being due to two linear but opposing beams of gas ejected in opposite directions from SS 433 at a speed of 80,000 kilometers per second, while the axis of these beams rotates once every 164 days. Furthermore, as the inclined axis sweeps past us, we see parts of both beams, with one of the beams creating redshifted lines from gas moving away



Long tails. Stretching three million light years away from this relatively motionless supergiant galaxy (seen as a radio image on the right), the radio-emitting tails cannot be explained by existing theories of galaxy tail formation. The detailed radio contour map (left) was made with the newly operational Very Large Array Radio Telescope; the galaxy's optical image is marked by the cross. The object lies one billion light years from the Earth.

from us, and the other causing blue-shifted lines from gas moving toward the Earth. Under this interpretation, the change observed in the emission wavelengths is not caused by a change in the velocity of the gas; it is caused by a change in the orientation of the gas as seen from the Earth.

There are still other questions that remain unresolved. We do not know the source of energy in this system, nor do we understand the mechanism that keeps the beams aligned. It is even possible that we are observing surface phenomena on a very compact object, such as a neutron star. Finally, this is the only object of its type observed, and the question remains whether other similar objects exist in our galaxy.

A "Tailed" Radio Galaxy

In the past decade, radio frequency observations of clusters of galaxies have resulted in the discovery of a class of sources known as "head-tail" radio galaxies. These radio sources have intense "heads" of emissions that coincide with individual galaxies in the clusters, and "tails" of emission with intensities that decrease to one side of the galaxies. The sources have an overall tadpole-like appearance.

The galaxies associated with head-tail sources are thought to be moving about the gravitational center of the clusters at enormous velocities. It is hypothesized that these active galaxies eject large quantities of plasma from their nuclei as they travel throughout the clusters. This tenuous plasma, after having escaped from the local confines of the galaxy, is decelerated by encountering the relatively dense intracluster medium that exists between the galaxies. This pressure eventually causes the plasma to come to rest with respect to the cluster gas. The galaxies themselves continue unimpeded through the cluster, leaving behind a trail of radio-frequency-emitting material.

There is a category of tailed sources known as "wide-angle tailed radio galaxies." These sources contain two separate tails with angles between the tails greater than ninety degrees. The sources resemble "L's" with the galaxy at the apex. These wide-angle tails are generally associated with massive galaxies at the centers of clusters.

Recently, Jack Burns of the National Radio Astronomy Observatory mapped the source 1919+479 with the Very Large Array at a wavelength of 20 centimeters. It is estimated that this object lies at a distance of one billion light years from the Earth, and the length of the tails in this source is about three million light years. This makes it the largest known source of this type. The source also contains a long (one-million-light-year) curved jet of radio emission which extends from one side of a compact radio source in the nu-

cleus. The tails and jet extend far beyond the optical image of the galaxy.

The combination of the extremely long radio tails, the curved jet, and the nature of the galaxy seem to pose a strong argument against the traditional model of tail formation by motion through an intracluster gas. The source is associated with a giant galaxy at the center of a rich cluster. Such supergiant galaxies are extremely massive and do not move significantly away from the cluster centers. However, the galaxy must move at least the length of the tails (three million light years) through the cluster to form a source such as 1919+479.

The contradiction between the known properties of the galaxy (stationary in the cluster) and the predictions of the model (rapid, prolonged motion through the cluster) would seem to rule out motion through an intracluster gas as a means of creating the tails in 1919+479. Although the radio tail model successfully explains the characteristics of the tadpole head-tail sources, a rethinking of our ideas on forming the L-shaped wide-angle tailed sources is needed. Several models are now being proposed that do not involve galaxy motion. Perhaps one of these will provide a satisfactory explanation of these phenomena.

Masses of Galaxies

Galaxies of stars appear in a wide variety of forms, the main classes being ellipticals and spirals. We have long known that the amount of rotation or angular momentum determines the forms, at least for spiral galaxies. If we can measure the changes in rotation velocity at changing distances from the center of the galaxy, not only can we see how rotation varies for galaxies of different structures, but we can also determine the masses of the galaxies.

Very few galaxies rotate like rigid bodies—that is, with a rotational velocity proportional to the distance from the center. Their inner parts rotate like rigid bodies, but farther out the rotational velocity increases very little, and the rotational velocity becomes almost independent of distances from the center or actually begins to decrease. The total mass can be estimated only when we can measure the rotation out far enough so that the rotation velocity begins to fall off.

To measure the rotational velocity, the slit of a spectrograph is placed across the galaxy along its major axis. The hot ionized gas in the galaxy gives rise to emission lines of hydrogen and other elements. By measuring the wavelengths of these lines as a function of the distance from the center, we are able (from the Doppler effect) to measure the velocities.

The observational problem of detecting and measuring lines becomes very hard when one gets very far from the center. In recent years Vera Rubin of the Carnegie Institution of Washington, using the 4-meter telescopes and the new, more efficient spectrographs at Kitt Peak and Cerro Tololo, has made a major advance by studying many spiral galaxies and showing that the rotation curves tend to show increasing velocities as far out as one can measure. The rotation curves start to decrease only in very few cases, as had been noted earlier from radio observations. Even earlier results using older optical telescopes and less effective spectrographs led us to believe that rotation curves did turn over in the inner parts of galaxies. This led to an underestimation of the mass of the galaxy in question.

This research has shown that galaxies in general are very much more massive than we had ever thought before. Since the mass must be present in the form of matter that does not radiate appreciably, there is much hidden mass in galaxies of stars. Whether it is present in the form of highly evolved stars like white dwarfs or neutron stars, or in black holes, or in some other form, we do not know.

Kitt Peak National Observatory

Kitt Peak National Observatory (KPNO), headquartered in Tucson, Arizona, was established in 1958 to strengthen basic research and education in astronomy in the United States. The observatory supports observational and theoretical research programs in stellar, solar, and planetary astronomy by visiting scientists. Engineering design and construction of telescope instrumentation also comprise a significant portion of KPNO's activities.

KPNO is operated by the Association of Universities for Research in Astronomy, Inc., under contract with NSF. The observing facilities on Kitt Peak, a 2,000-meter (6,875-foot) mountain 90 kilometers (56 miles) southwest of Tucson, include ten stellar and four solar telescopes.

KPNO scientists and engineers are playing a major role in the planning for the next generation of optical and infrared telescopes. In January 1980 they organized an international conference in Tucson on telescopes for the 1990s. At that meeting, new and radical designs for very large (approximately 15-meter aperture) telescopes were discussed. Several groups both in the United States and abroad are carrying out studies that may lead to the construction of such a telescope in the next few years.

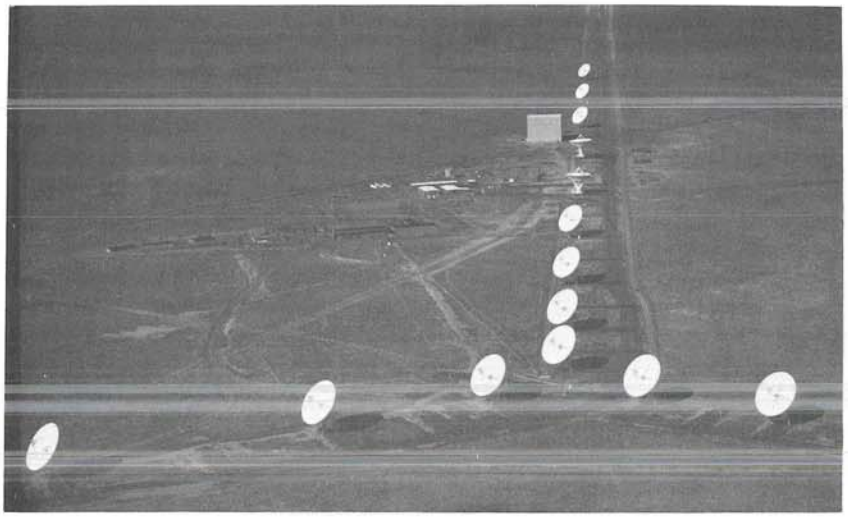
Cerro Tololo Inter-American Observatory

As the only Southern Hemisphere astronomical facility of any kind available to the U.S. scientific community at large, Cerro Tololo Inter-American Observatory (CTIO) provides a broad range of observational instruments for optical and infrared astronomy. These include a 4-meter

reflector, the Southern Hemisphere's largest telescope.

Operated by the Association of Universities for Research in Astronomy, Inc., under contract with NSF, the observatory headquarters are located in La Sereña, a coastal town 475 kilometers (295 miles) north of Santiago, the capital of Chile. CTIO's eight telescopes are on Cerro Tololo, a 2,200-meter (7,200-foot) peak on the western slopes of the Andes, 80 kilometers (50 miles) inland from La Sereña.

The portion of sky observable from CTIO includes the central bulge of our galaxy and various objects distributed about the galactic center. Among these are the globular clusters, fossil remnants of an early evolutionary period of the Milky Way, and the Large and Small Magellanic Clouds, the closest external galaxies to our own.



Operational. In the past year the final ten antennas have been installed, bringing to 27 the number operating together at the Very Large Array Radio Telescope in New Mexico. This view shows 14 of them clustered around the apex of the wye configuration; they can be spread over 24 kilometers for high-resolution studies.

National Radio Astronomy Observatory

The National Radio Astronomy Observatory (NRAO) is operated by Associated Universities Inc., under contract with NSF. NRAO has telescopes at three sites and its headquarters and a main data-processing center in Charlottesville, Virginia. In the past year the fully steerable 43-meter telescope at the Green Bank observing site in West Virginia has been equipped with a new low-noise 5- to 25-GHz maser receiver. This wide band system improves the efficiency of the telescope, allowing new searchs for molecular species and observation of extragalactic sources by the techniques of very long baseline interferometry. The 91-meter telescope at that site received a traveling feed track able to carry the new cryogenic-cooled maser receivers in the 300- to 1,000-MHz range.

At the 11-meter millimeter wave telescope on Kitt Peak, Arizona, low-noise, wide-frequency-range mixer receivers have been developed with particular application to the observation of X-ray quasars. During the past year the Very Large Array in Socorro, New Mexico, has grown from 17 antennas on an 18-kilometer baseline to the full complement of 27 antennas on a 24-kilometer baseline. With the delivery of the second antenna transporter, formal scheduling of the array into different configurations has begun.

National Astronomy and Ionosphere Center

The National Astronomy and Ionosphere Center (NAIC) has its major observing facility located near Arecibo, Puerto Rico. The main instrument is the 305-meter (1,000-foot) diameter antenna—the world's largest radio/radar telescope. NAIC is operated by Cornell University under contract with NSF.

Scientific activities are conducted in radio astronomy, radar astronomy, and atmospheric science. New equipment and systems are continually being developed to meet the needs of in-house and visiting scientists. The telescope surface has recently been surveyed and faired to bring the entire surface (about 8 hectares) within a few millimeters of being a true spherical surface.

During 1980 NAIC completed the construction of a major new facility for atmospheric research located about 16 kilometers (10 miles) north of the Arecibo Observatory. This facility, the high-frequency heating facility, includes four transmitters delivering a total of 800 kilowatts to an array of log periodic antennas. The facility is now operational and is being used to study the ionospheric plasma in conjunction with the 430-megahertz radar system of the 305-meter telescope.

During 1980 a major program was the mapping of the surface of Venus with the high power S-band planetary radar system. Because of its dense cloud cover, it is impossible to see the surface of Venus by optical means. New equipment and techniques allowed for mapping a significant portion of the surface at resolutions as precise as 4 kilometers.

Sacramento Peak Observatory

Sacramento Peak Observatory (SPO) is one of the world's major centers for research dealing with the physics of the Sun. Located at an elevation of 2,760 meters (9,055 feet) in the Lincoln National Forest in New Mexico, SPO has a number of unique solar research facilities and is committed to the application of the most advanced technology to research on the Sun.

The very-high-spatial-resolution images of the vacuum tower telescope can be directed to an impressive array of instruments especially designed to reveal details of the magnetic fields and gas flows in the solar atmosphere. The scope and variety of the observations carried out during the past year can be appreciated from the following sample of observing programs: velocity fields in solar flares and sunspots; dependence of the amplitude of the solar five-minute oscillation on height in the solar atmosphere; limb brightness oscillations; flare buildup studies; and mass ejection in active regions.

Observations in the form of magnetograms, spectral line measurements, and coronograph and polarimeter measurements are used to study active regions of the Sun and the structure and dynamics of the solar corona. Scans of the green coronal line and maps of the solar magnetic fields are made daily and supplied to such agencies as NOAA, NASA, and the Air Force for use in prediction of solar events that may affect geomagnetic activity.

Atmospheric Sciences

Atmospheric sciences is a discipline in which knowledge of physics, chemistry, biology, and other sciences is combined to improve the understanding of the Earth's atmosphere—from the planet's surface to outer space. Through seven grant programs and support of the National Center for Atmospheric Research and the National Scientific Balloon Facility, NSF supports basic research on a wide range of subjects. They include the physics, chemistry, and dynamics of the Earth's upper and lower atmosphere; the acquisition of data on physical processes in the troposphere and stratosphere that will aid in understanding the general circulation of the atmosphere and the physical basis of climate; and climate processes and variations, as well as smaller-scale, shorter-term phenomena leading to greater knowledge of weather processes.

In 1980 NSF put special emphasis on research in mesoscale meteorology, atmospheric chemistry, incoherent scatter radar, and the variability of past and present climates—as well as on initial analyses of data collected during the Monsoon Experiment (Winter and Summer MONEX—part of the largest international weather observing program ever conducted, the Global Weather Experiment under the Global Atmospheric Research Program).

One of the objectives of the Global Weather Experiment, recently completed, was the acquisition of a detailed set of observations on the behavior of the global atmosphere, with particular emphasis on the tropics and Southern Hemisphere. This global data base will now make possible new theoretical, experimental, and diagnostic studies on weather and climate. In particular, this three-dimensional, worldwide atmospheric data is needed to test and improve the mathematical models of global circulations used for forecasting and research.

MONEX, the largest and most ambitious scientific field program ever mounted to study the Asian monsoons, was completed early in 1980. It is sponsored jointly by the World Meteorological Organization of the United Nations and the International Council of Scientific Unions. More than 20 nations participated in the yearlong field phase of MONEX, including the United States, the Union of Soviet Socialist Republics, and the Peoples Republic of China, and most of the Asian nations of the monsoon regions. NSF had the lead agency responsibility for U.S. participation in MONEX.

Monsoons are important for several reasons. They are the most energetic regional circulations of the Earth's atmosphere and affect weather and climate on a global scale. They also exert tremendous influence on the agriculture, economy, politics, and health of a major portion of the Earth's population. Forecasting the monsoon's behavior, in particular the onset of the monsoon, is, therefore, one of mankind's most important single predictions.

In most years the onset of the Indian monsoon is accompanied by the formation of an intense vortex, or storm, over the Arabian Sea. A detailed examination of the onset vortex and the commencement of heavy monsoon rains over central India has revealed that the kinetic energy of the winds over the Arabian Sea increases tenfold about one week prior to the occurrence of the rains. Using data from a variety of MONEX observing platforms, Tiruvalam N. Krishnamurti of Florida State University calculated the day-by-day changes in the atmospheric kinetic energy—a measure of the wind speed. As expected, he found that the wind speeds increase over the Arabian Sea prior to the beginning of rains over India. What was unex-

pected was the sharp and intense increase and the fact that it occurred a week before the rains. If this finding for the 1979 monsoon proves to hold in general, it may provide a means of predicting, about a week in advance, one of the major weather systems on Earth.

Climate Modeling

Climate models—mathematical simulations—are important in improving our knowledge of the Earth's climate system, which consists of the atmosphere, oceans, ice, snow, and surface of the Earth itself. The system is driven by the differential incidence of solar radiation. A hierarchy of climate models—from simplified ones designed to model the basic energetics of the system to complex ones intended to reproduce detailed atmospheric and oceanic circulations, ice movement and development, and interactions with each other and with the surface of the Earth—have been or are in the process of being developed.

Currently, climate modelers are attempting to determine what effect the predicted large increases in atmospheric carbon dioxide will have on climate. If present rates of fossil fuel consumption and deforestation continue, it is estimated that the carbon dioxide concentration will double in less than 100 years. Because carbon dioxide is a very efficient absorber of radiant energy in certain longer (infrared) wavelengths, it retards the loss of long-wave radiation from Earth back to space and keeps the lower atmosphere warmer than it would be in the absence of carbon dioxide. Hence, it is to be expected that an increase in carbon dioxide will lead to a warming of the troposphere. But the question is: How much and how rapidly?

A number of so-called "equilibrium" models agree in predicting that the global atmospheric temperature will increase by 2 to 4°C if carbon dioxide is doubled. Partly because of the concomitant melting of Arctic sea ice, the increase in the North Polar region is predicted to be much larger, up to 11°C according to one model. But all of these model results assume that the oceans, which play a dominant role in regulating the temperature of the climate system, have zero capacity to absorb heat and to buffer this change. In other words, the models treat them as shallow swamps which adjust immediately to changed radiant energy conditions. While such an assumption may possibly represent conditions to be expected after complete thermal equilibrium has been reached, the period of time required for the deep oceans, with their slow circulation and large heat capacity, to adjust to the new radiational conditions is unknown.

Stephen Schneider of NCAR and Starley Thompson of the University of Washington have continued to apply their energy balance model to the problem of the transient response of the surface temperature to carbon dioxide increases. Previously, they pointed out that the vertical mixing between upper and lower oceanic layers would increase the effective long-term heat capacity of the ocean, thereby delaying for decades the approach of the global average surface temperature toward its equilibrium response. They have now considered the approach toward equilibrium of individual latitude zones under two different assumptions for the ocean mixed-layer depths: (1) a uniform global value and (2) values dependent on latitude.

Under both sets of assumptions (but particularly for the second assumption) they found that various latitude zones approached their equilibrium responses for a given carbon dioxide increase at different rates. For example, 60°S, which is all ocean, approached its equilibrium value about one-half as fast as the equator. These results imply that different regions of the Earth will have different transient responses to carbon dioxide increases. Consequently, regional climatic anomalies predicted from the equilibrium response of a climatic model driven by a doubling of carbon dioxide are likely to be significantly different from those given by the transient response driven by a more realistic time-dependent, exponential increase in carbon dioxide. The study suggests that considerably more attention must be paid to the characteristics of the atmosphere/ocean/ice system that govern the transient response of the surface temperature to external forcings over decadal time scales.

Another important aspect of the fossil-fuel/climate problem concerns the early detection of a surface warming due to carbon dioxide increase, if and when it occurs. Roland Madden and Veerabhadran Ramanathan at the National Center for Atmospheric Research (NCAR) examined this question and concluded, judging from analysis of interannual variability of surface temperatures at 60°N, that the warming predicted by current climate models should be detectable between now and the year 2000. They also discussed the feasibility of using satellite measurements to isolate carbon dioxide effects. Ramanathan, with Robert Cess and Ming-Shih Lian of the State University of New York at Stony Brook, has described the radiative heating of the troposphere and surface (due to increased carbon dioxide) as a function of latitude and season and inferred the resultant latitudinal and seasonal warming of the surface using an energy-balance climate model.

Atmospheric Effects of Mount St. Helens

When the Mount St. Helens volcano in southern Washington became active on March 27, 1980, after a long quiescent period, it caused a

Atmospheric effects. In April 1980 NCAR scientists, responding to the early volcanic activity of Mount St. Helens, made aerial surveys to study the plume, shown here prior to an eruption. Further studies were carried out after the major explosion on May 18, in which material rose into the stratosphere.

flurry of interest among scientists across the country. This initial activity, scientifically interesting by itself, also gave warning of a possible major eruption (which, of course, did occur two months later). Such an eruption can have global atmospheric effects in addition to the trauma to the immediate area caused by earthquakes, mudflows, and heavy ash fall. For that reason, scientists at the National Center for Atmospheric Research sampled the ash cloud (plume) of Mount St. Helens in April 1980 using a specially instrumented aircraft. Those and later results should help clarify theories concerning the possible effects of volcanoes on climate and weather.

It is well known that volcanic eruptions can have significant effects on the chemical balance of the stratospheric ozone layer, which protects the Earth from solar ultraviolet radiation. Sulfur dioxide from eruptions can combine with hydroxyl radicals to form sulfuric acid in the stratosphere. Other chemicals, such as carbonyl sulfide, may also enter the lower atmosphere (troposphere) and work their way upward into the stratosphere, eventually reacting with light to form more sulfuric acid. Local toxic effects might be caused by such gases as mercury vapor.

There is considerable evidence that volcanoes may also have long-term climatic effects. Backscattering of light by very fine ash particles and sulfuric acid can cause a reduction in the amount of light reaching the Earth, with concomitant changes in precipitation and cooling patterns.

Retired NCAR scientist Richard Cadle flew in an NCAR Queen Air through the Mount St. Helens plume in April, gathering particle and gas samples. The plane was outfitted with evacuated canisters to gather samples of the gases for chromatographic analysis, special filters for collecting particles, a water sampler developed by the U.S. Geological Survey to determine how much of the water in the volcano's cloud originated from groundwater and how much from the Earth's mantle, a quartz microbalance impactor for determining the size distribution and composition of particles (from NASA), and filters for collecting larger ash particles (from Michigan Technological University). Photos of the plume were also taken.

Although a weak odor of sulfur dioxide and hydrogen sulfide could be detected in the aircraft cabin, only negligible amounts of sulfur compounds were measured. Cadle believes that the volcano's low sulfur output was because its eruptions were phreatic, caused by ground water hitting hot magma, rather than magmatic, characterized by hot gases from molten lava. Magmatic eruptions are more likely to inject sulfur compounds into the atmosphere. At the time of the NCAR flights, the eruptions from Mount St. Helens reached only six kilometers above sea level. Because of the lack of sulfur dioxide and the large size of the ash particles in the plume, which were too large to rise into the stratosphere, that eruption was not likely to have much impact on weather and climate.

The major eruption on May 18 reached stratospheric levels, and preliminary results from samples taken by another research group at the University of Washington indi-

cated the presence of hydrogen sulfide in the plume. Cadle strongly suspects that the presence of a sulfur compound indicates that the May 18 eruption may have been magmatic; it was also a much hotter eruption than would be expected from a typical phreatic event, and particle sizes in the cloud were much smaller than previously. A "bulge" that developed in the mountain before the May 18 eruption was also indicative of a buildup of magma.

The May 18 eruption provided other unique opportunities for research on the impact of volcanic emissions on the atmosphere. David J. Hofmann and James M. Rosen of the University of Wyoming flew balloon-borne instruments into the volcanic plume over Laramie, Wyoming, and detected condensation nuclei throughout the lower stratosphere up to an altitude of 26 kilometers. This is believed to be the first direct observation of particles of this small size in volcanic injections to the stratosphere. Particles in this size range act as condensation centers and precursors of larger aerosol particles capable of scattering sunlight and affecting the heat balance of the Earth. The finding of volcanic injection of condensation nuclei directly into the stratosphere provides an important new step toward the understanding of natural versus man-made influences on the Earth's climate.

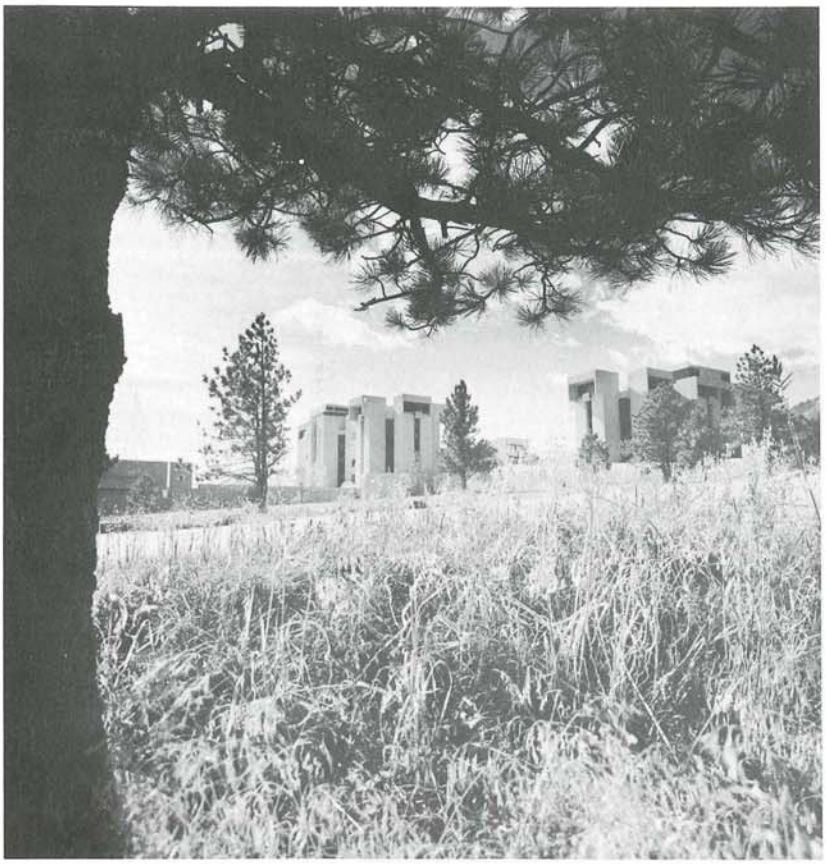
Equatorial ballooning. Scientists from the National Scientific Balloon Facility launch a balloon from a rural area in Juazeiro do Norte, Brazil, to begin a high-altitude study of sources of trace gases in the atmosphere.

Solar Maximum Year

NSF and NASA are jointly supporting the 1979–81 Solar Maximum Year (SMY), which reached a peak in observational activity corresponding to the maximum in the solar cycle in 1980. NASA is responsible for the spacecraft observations of the Sun, most of which are provided by a dedicated satellite—the Solar Maximum Mission (SMM). NSF is responsible for the ground-based research at universities and the National Centers. One of these centers, NCAR, is also participating directly in SMM, which carries seven scientific instruments, including the NCAR coronograph/polarimeter. It was launched into earth orbit on February 14, 1980, to study flares on the Sun during the 1979–81 peak of its 11-year sunspot cycle. The NCAR instrument will help to study the evolution of the Sun's corona and the transient activity associated with flares.

Like the instrument used on the Apollo Telescope Mount of the Skylab orbiting solar observatory (which took measurements during the solar activity "minimum" in 1974), the NCAR telescope makes it possible to view the extremely thin corona by using an external occulting technique to create an artificial eclipse. The satellite is complemented by associated observing programs at more than 100 ground-based observatories, including a new telescope system at the NCAR High Altitude Observatory observing station on Mauna Loa in Hawaii.

The ground-based observations have already shown significant results. In 1979, for example, observations at the South Pole dramatically confirmed previous measurements made at Stanford University by John Wilcox that the Sun does indeed oscillate with a period of approximately 160 minutes. These oscillations result from motions inside



National Center for Atmospheric Research. NCAR headquarters and laboratories are located in Boulder, Colorado. Separate facilities are maintained for large field experiments.

the sun—a region not easily accessible to direct observation. Thus, we have an important new diagnostic tool which should greatly improve the understanding of the internal dynamics of the Sun and the impact of such dynamics on solar activity, such as the 11-year variation. Observations at the Big Bear Observatory (operated by the California Institute of Technology with NSF support) have confirmed for the first time that solar flares are associated with large, rapidly changing magnetic fields. Furthermore, recent results at Mount Wilson Observatory show that the sun is undergoing torsional oscillations. Thus, the SMY is proving to be a very successful program, with discoveries of unprecedented accuracy and resolution. Even the Sun has cooperated by providing one of the most active maxima ever seen.

National Center for Atmospheric Research

The National Center for Atmospheric Research (NCAR) is a major research facility devoted to large-scale atmospheric research projects in cooperation with universities and other organizations. The National Scientific Balloon Facility (NSBF) provides the necessary support for scientific research requiring extended high-altitude experiments. These two facilities are operated under contract with NSF by the University Corporation for Atmospheric Research, a consortium of 47 U.S. and 2 Canadian universities that have doctoral programs in the atmospheric sciences.

NCAR research is aimed primarily at improving climatic analysis and knowledge related to weather prediction; obtaining better understanding of atmospheric chemistry, air quality, and severe convective storms; and studying the interactions between the Sun and the Earth's atmosphere. In addition to a variety of other facilities, NCAR also provides computing resources for the atmospheric sciences, including a CRAY-1, one of the world's fastest computers, thus enabling scientists to develop and use complex models of atmospheric phenomena and analyze the large amounts of data that are an essential part of exploring the atmosphere.

NCAR's field programs during the year included an aircraft flight series to Mount St. Helens to sample ash and vapor emissions from the volcano's ash cloud, balloon launches in Brazil to measure atmospheric trace gases and their sources, and an expedition to view the total solar eclipse over the tropics. An NCAR telescope was launched aboard the Solar Maximum Mission satellite to study solar flares during the peak in the 11-year sunspot cycle.

During the past year NSBF conducted 91 scientific balloon flights, 73 in support of atmospheric science and experiments in high-energy astronomy. Major development programs included testing of a prototype balloon system for global long-duration flights and a new system for carrying heavier payloads than have been flown in the past. NSBF also provided balloon-borne measurements to verify those made by the Limb Infrared Monitor of the Stratosphere (LIMS) experiment aboard the NASA Nimbus-7 satellite to determine worldwide atmospheric chemical composition.

Earth Sciences

The earth sciences, which have seen rapid development during the past two decades, continued at an accelerated pace in 1980. At least three major factors are at play. First, there is mounting awareness of the importance of earth science to the common concerns of mineral and fuel resources, disruptive geologic phenomena such as earthquakes and volcanic eruptions, and hazardous waste disposal. Second, scientists have a growing arsenal of new instruments and techniques which are revolutionizing their ability to measure the physical world and treat vast amounts of data. Third, the development of quantitative models, including but not limited to the unifying theory of plate tectonics, has led to more satisfactory interpretations of geologic phenomena and to fruitful new lines of investigation.

As often happens in science, the most exciting action is taking place along interdisciplinary boundaries. Advances in our understanding of mantle dynamics are coming from the interactions of isotope geochemistry, seismology, and ultrahigh pressure research. Petrologists, physical chemists, and fluid dynamicists are challenging classical concepts of magma differentiation with radical models employing double diffusion, liquid immiscibility, and oscillatory reactions. Specialists in paleomagnetics, climate dynamics, tectonics, and stratigraphy are combining their knowledge to create paleogeographic maps of the world which go back much farther than the record in existing ocean basins. The discovery of a widespread anomalous concentration of the trace metal iridium at the Cretaceous-Tertiary boundary has inspired geologists, paleoecologists, and physicists to consider extraterrestrial causes for mass extinctions of life in the geologic record.

A major new trend is increased interest in the continents and their oceanic margins. Inasmuch as the 1960s could be characterized as the decade of lunar exploration and the 1970s as the decade of oceanic exploration, it is apparent that, although many scientists will continue to pursue basic research in extraterrestrial and oceanic regions, the 1980s will see renewed interest in the constitution, dynamics, and evolution of the continents, their margins, and subjacent mantle. Some of the major scientific objectives of this effort are characterizing the differences between continental and oceanic lithospheres and subjacent aesthenosphere, measuring plate motions directly, developing dynamic models of mantle behavior, understanding intraplate tectonism and volcanism, understanding plate boundary phenomena, and developing quantitative models of lithospheric evolution. Each of these general objectives has important implications for the needs of our society as well as for the growth of earth sciences.

Many earth science projects in the 1980s will be expensive, extensive, and multidisciplinary. More research will be undertaken by teams of investigators from several disciplines and often from several institutions. In some situations cooperative arrangements will develop between academic, government, and industrial organizations. Although such consortia will never replace the individual investigator, it is clear that some objectives can be reached only by coordinated efforts. In 1980 NSF supported major cooperative programs in deep seismic reflection profiling, a continental drilling program of in situ measurements and core studies at Continental Edison's deep borehole in Illinois, a U.S.-Japan-Canada cooperative research project on the genesis of volcanogenic massive sulfide deposits, and a U.S.-India cooperative investigation on the Precambrian geology of India. Possible future endeavors include a joint U.S.-Canada-Mexico multidisciplinary study of the transitions from oceanic to cratonic lithosphere of North America.

Despite periodic shifts in research objectives and changing styles of funding, however, the goal remains as it has been: to support research excellence anywhere in the general fields of geology, geochemistry, and geophysics.

The Eruption of Mount St. Helens

In January of 1980 NSF funded a proposal to make a detailed geochemical study of Mount St. Helens in order (among other objectives) to document trends that might predict future eruptive behavior. This aspect of the study was preempted on May 18 when the mountain exploded in a startling display of volcanic force which substantially altered the field area and focused the attention of the Nation on this and the other Cascade volcanoes. This study and others like it provide the scientific basis for understanding and predicting volcanic phenomena. In the case of Mount St. Helens, earlier geologic studies (some supported by NSF) enabled the U.S. Geological Survey in 1978 to predict an eruption of Mount St. Helens in this century, and by the time of the May 18 blast the mountain was under constant surveillance.

When the dust of May 18 had settled, it was apparent that the eruption had provided an opportunity (and pressing need) for immediate field and laboratory studies of the volcanic processes and products and their effects upon the region. The most urgent matters relating to public health, safety, and environmental

impact were dealt with predominantly by other State and Federal agencies, but there was also an opportunity to make unique scientific observations if studies could begin immediately.

Accordingly, on May 30 NSF invited brief proposals to which it would respond immediately; AAEO programs received 87 within 7 weeks of the announcement. Funds were available to make 18 awards (13 in earth sciences, 3 in atmospheric sciences, 1 in ocean sciences). All of the funded projects dealt with transient phenomena or features that had to be investigated immediately. The awards in earth science included support for collecting and analyzing gas, analyzing chemical and petrographic compositions of fresh ash, drainage development and landform evolution, concentrations of short-lived radionuclides in the effusive materials, and installing various instruments such as infrared and infrasonic detectors and automated sediment traps to monitor future volcanic activity.

Some preliminary results are available from these special projects, and others will be forthcoming in abstracts and short reports at scientific meetings. Full reports are not expected for several months. Present indications are that the recent events bore many similarities to past eruptions. If the past record is an indication of the future, Mount St. Helens will remain active for several more years. The preliminary studies made possible by the special awards are only precursors to major efforts at monitoring and studying this volcano during its active period. These investigations will increase our understanding of past, present, and future Cascadian volcanism.

Fine Structure of the Crust and Upper Mantle

Significant new results have been obtained from the Consortium for Continental Reflection Profiling (COCORP) project since the NSF *Annual Report* for 1979, in which results of a seismic reflection profile extending from eastern Tennessee through North Carolina to near Augusta, Georgia, were described. This profile has now been extended to near the Atlantic Coast at Savannah. This is the first COCORP profile to end near the sea, providing an opportunity for continuation offshore. The extended profile provides further evidence for large-scale overthrusting of older crystalline rocks of the Blue Ridge and Piedmont provinces of the Appalachians onto sediments of a Paleozoic continental margin. This result has major implications for interpreting sites of continental collision elsewhere. A practical point is that the buried sediments that underlie a large area of the southern Appalachians may contain trapped hydrocarbons.

Sampling gases. Geochemists from the Universities of Arizona and Maryland collect gases from a hot (350°C) vent in fresh pyroclastic flows on Mount St. Helens. This and other prompt investigations of the effects of the May 18th eruption were supported by special "quick-response" grants.

COCORP lines were also recorded in southwestern Oklahoma to investigate the deep structure of the Wichita Mountains and the Anadarko basin, and to investigate further the nature of the basement rock under the Hardeman-Hollis basin, the site of the original COCORP testing in Hardeman County, Texas, in 1975. The prominent flat-lying reflectors in the Precambrian basement originally discovered beneath the Hardeman County basin have been traced over an area of about 2,500 square kilometers in Texas and Oklahoma. These reflectors, at depths of 7 to 10 kilometers, are abruptly terminated at their northeast margin by a high-angle fault along the Wichita Uplift, apparently the ancestral predecessor of the Pennsylvanian Burch fault. By analogy with worldwide mid-Proterozoic basins, these reflectors may represent thick deposits of terrigenous sedimentary and acid volcanic rocks.

The strong continuous reflections from the crust in Oklahoma and Texas no doubt extend beyond the boundary of the surveyed area and are prime targets for further surveys. Once these reflectors are delimited and identified, the geology of a very large volume of continental crust, extending to midcrustal depths, will be far better known.

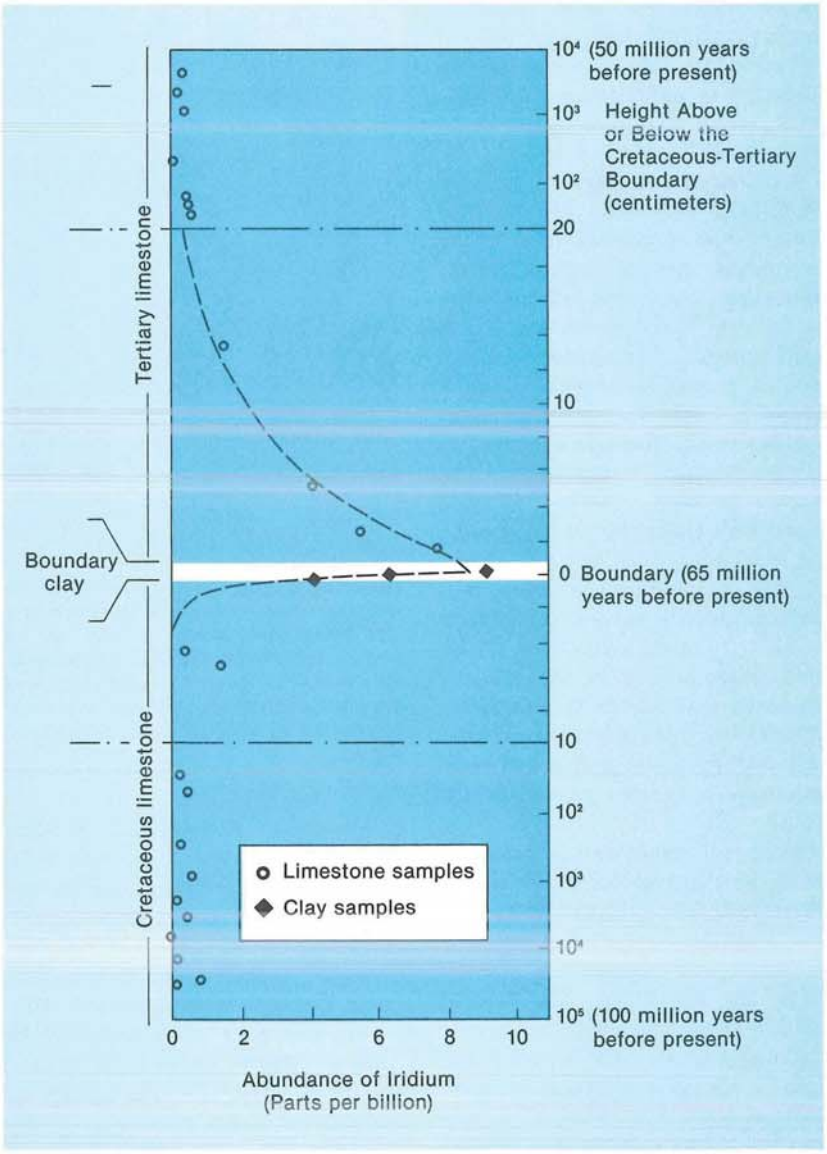
In the late fall of 1979 COCORP began a seismic traverse across the Midcontinent Geophysical Anomaly (MGA) in northeastern Kansas. This linear gravity high and associated magnetic anomaly, which extends over 3,000 kilometers from Abilene, Kansas, to Lake Superior, is the most pronounced geophysical anomaly in the central United States. Many believe it represents a buried Precambrian rift system. The Kansas survey is also designed to cross the Nemaha Ridge, a buried Paleozoic uplift east of, and perhaps related to, the MGA in Kansas. Although the planned traverse is over 250 kilometers long (including 4 cross lines), only about 85 kilometers of the east-

ern end were completed in 1979 before inclement weather forced a halt. Preliminary data show strongly dipping reflectors at depths of 15 to 30 kilometers. Completion of the traverse is planned for late 1980.

The Laramie Range of southeastern Wyoming, at the eastern edge of the North American Cordillera, is the definitive example of the late Mesozoic-Early Tertiary Laramide mountain-building and was affected by the Late Paleozoic Ancestral Rockies event. In addition, a fundamental Precambrian crustal boundary, which may represent a San Andreas-type transform fault or an ancient subduction zone, trends northeast across the range, separating 1.7 billion-year-old rocks on the south from 2.5 billion-year-old rocks on the north. To continue studies of Laramide basement uplifts, investigate the nature of the transition between the Great Plains and the Rocky Mountains, and study the nature of the Precambrian shear zone, COCORP recorded 186 kilometers of profile reflection data from August to October of 1979. Preliminary seismic sections across the Laramie Range suggest that there may be fundamental differences in crustal character on either side of the Rocky Mountains and that they may have existed prior to Laramide deformation. Additional processing of the data is expected to clarify these relations.

Iridium and the Cretaceous-Tertiary Boundary

The recent discovery of unexpectedly high levels of iridium and other platinum group elements in marine sediments deposited during the transition from the Cretaceous to the Tertiary periods (65 million years ago) has thrown new light on the mystery of the extinction of the dinosaurs and other Mesozoic organisms. The iridium anomaly was first noted by scientists at the University of California, Berkeley, in sediments collected near Gubbio, in the Italian Apennines, during a collaborative study by U.S. and European scientists on relationships between biostratigraphic and magnetic-reversal correlations.



Boundary anomaly. Measurements across a one-centimeter-thick clay layer separating limestones of the Cretaceous and Tertiary geologic periods show a 30-fold jump in the trace element iridium. The iridium could have come from a large meteorite impact; such an event may have been associated with the extinction of many life forms—including dinosaurs—at that time.

Iridium concentrations near the Cretaceous-Tertiary boundary at Gubbio are 30 to 160 times those found in ordinary deep-sea sediments. Subsequent work has shown that iridium and other noble metals are also anomalously abundant in a

thin layer of clay that marks the boundary in Denmark and that they occur in the relative proportions found in chondritic meteorites. Because iridium and related elements are depleted in the Earth's crust relative to their meteoritic abundances, the high concentrations and chondritic ratios in the boundary sediments are consistent with an extraterrestrial source. The Berkeley group suggests that the source of the extraterrestrial matter might have been a meteorite, as large as ten kilometers in diameter, which would have thrown up enough pulverized terrestrial debris to cut off solar radiation and suspend photosynthetic processes for several years. This dust, containing the meteoritic component, eventually settled in the oceans to form the thin clay layers found in Italy and Denmark.

Although the impact hypothesis requires further testing, the concept of a brief suspension of photosynthetic processes fits well with the known pattern of Cretaceous extinctions: All dinosaurs, as well as old marine and flying reptiles and many groups of marine plants and invertebrates, perished. The surviving life forms included organisms such as land plants that might have been able to regenerate from root systems, seeds, and spores, and primitive mammals, small reptiles, and marine invertebrates that could possibly have survived the disruption of normal food chains by subsisting on insects and decaying vegetation during the period of diminished sunlight.

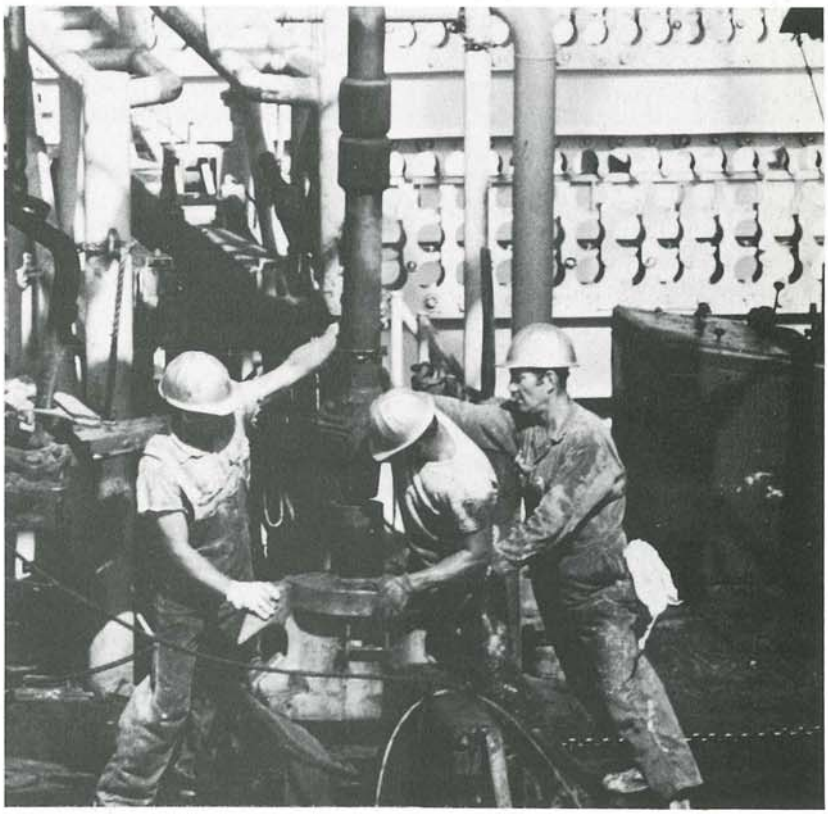
But before this hypothesis can be accepted major questions must be addressed. One of these is to what extent the extinctions occurred in different places at the same time. The marine section at Gubbio is important in this respect because it has been used as the basis for the best detailed correlations between biostratigraphy and the chronology of worldwide magnetic reversals and because it is believed to represent a continuous sedimentary record across the Cretaceous-Tertiary boundary. Another question is the time span involved. If the impact hypothesis is correct, worldwide extinctions were instantaneous in a geologic sense. Although there are still differences of opinion on the validity of the impact hypothesis, it has given a sharp focus to several other groups working on similar problems under NSF sponsorship.

Ocean Drilling

In 1980 the ocean sediment coring program, previously part of NSF's earth sciences programs, was restructured into an independent unit consisting of two major activities: the deep sea drilling project and the ocean margin drilling project.

Deep Sea Drilling Project (DSDP)

The DSDP, funded by NSF since 1966, has as its fundamental objective the exploration of the Earth's surface beneath the oceans. This goal



Deep Sea Drilling Project. Workers manipulate drilling equipment aboard D/V *Glomar Challenger* in 1980, the twelfth year of operation of this highly productive program to study the geology of the ocean floors.

is met by deep-ocean drilling and coring with the unique ship, the D/V *Glomar Challenger*. Joint Oceanographic Institutions, Inc. (JOI, Inc.), a nonprofit corporation chartered from among ten major ocean-going research institutions, provides scientific planning for the project in connection with the international JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling) scientific committees and panels. Scripps Institution of Oceanography has the prime responsibility for the operations of DSDP. Global Marine, Inc., operates the drilling vessel under subcontract to Scripps.

Operations with *Challenger* began 12 years ago in August 1968. As of August 1980, nearly 900 holes had been drilled at about 530 different sites, during 74 cruises (legs), each of which lasted about 55 days. Almost 70 kilometers of cores had been recovered from every major oceanic area except the Arctic.

From the outset, numerous foreign scientists made contributions to DSDP—as participants aboard *Challenger*, by studying samples and data, and as members of advisory panels. Thus, in 1975, the international phase of ocean drilling (IPOD) was initiated to cement the program's international spirit. IPOD is presently supported annually at the level of $1.25 million from each of five partner countries—the Federal Republic of Germany, France, Japan, the U.S.S.R., and the United Kingdom.

During 1980 *Challenger* operated in both the Pacific and the Atlantic. Leg 68, begun during the previous fiscal year, was a full-scale test of a new coring tool deployed only once before, the hydraulic piston corer. The corer enables *Challenger*, for the first time, to recover undisturbed cores from the soft, unconsolidated upper sedimentary layers of the ocean floor. (This tool was described in the NSF 1979 *Annual Report*.) The test leg was highly successful, recovering some 300 meters of soft sediments at one site in the Caribbean; these sediments appear to span an undisturbed depositional record of the past 8 million years. Materials from this leg will be used to study the details of climatic changes that occurred during that time interval.

After completing the testing leg in the Caribbean, the ship returned to the Pacific and completed two legs (69 and 70) that were dedicated to investigating the "Galapagos Mounds," an area off northwest South America. These mounds on the ocean floor are formed by hot, mineral-laden waters issuing from submarine vents in geologically very young oceanic crust. They are features of basic geological interest—examples of a very active zone of the ocean crust—and are also of considerable interest as potential sites of mineral deposits. Both conventional rotary drilling and hydraulic coring were used in the mounds area. The samples recovered will allow the study of the chemistry, structure, and history of this part of the Earth's crust.

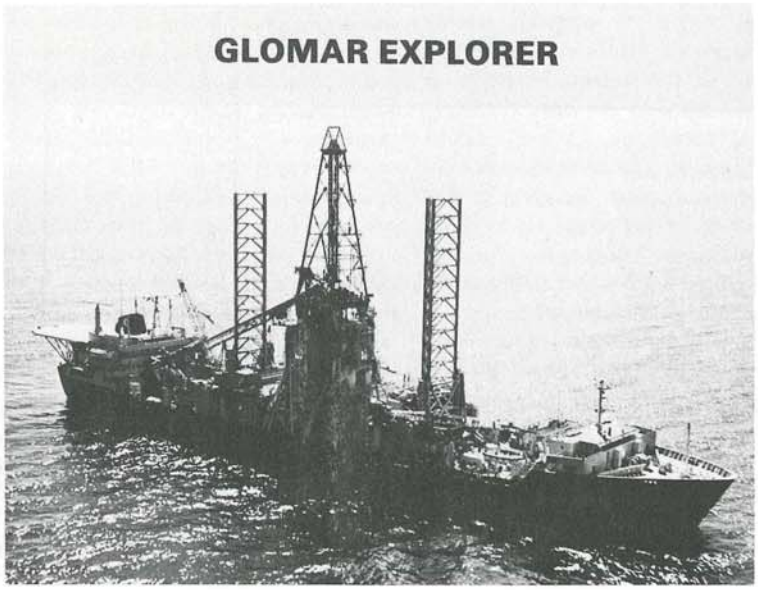
Following the Galapagos drilling, *Challenger* moved into the southern Atlantic to begin a five-leg program of South Atlantic drilling and research, which was still under way at the end of the year. This program is to study the history of the changes in oceanic circulation patterns associated with the opening and widening of the Atlantic Ocean and with the establishment of glacial conditions in the Antarctic.

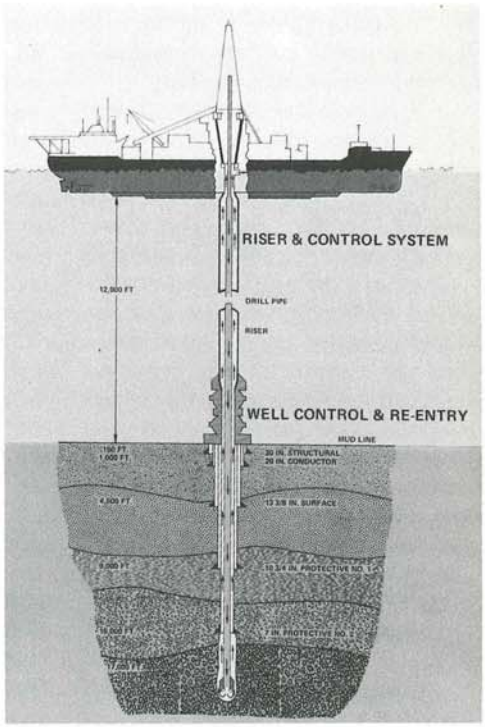
It is generally accepted that the Atlantic Ocean began to form about 200 million years ago as a result of rifting and breaking apart of one, or possibly two, gigantic continental blocks. The Americas on one side, and Europe, Africa, and Asia on the other, then slowly drifted apart as new Atlantic oceanic crust spread out between the pieces. Parallel to these very slow but sweeping geological changes, Atlantic oceanic water circulation patterns evolved, bringing about changes in climates, sedimentation patterns, and the distribution and emergence of life forms. The young South Atlantic that was thus being formed was a temperate sea. But about 30 to 40 million years ago antarctic glacial conditions appeared, and modern environmental patterns slowly set in. It is this complex geological and environmental evolution that *Challenger* is addressing in the South Atlantic program, comprising Legs 70 through 75, in which the new hydraulic corer is playing a prominent role.

Ocean Margin Drilling

A major scientific endeavor to improve the basic understanding of the nature and origin of the Earth has been under consideration at NSF for the past several years. This new project (OMDP) is the result of planning and evaluation by scientists, engineers, government officials, and industry executives. Planned as a combined effort by academia, government, and private industry, it builds on the very successful global reconnaissance done with *Glomar Challenger* in the deep sea drilling project. Its approach is to investigate the geology and paleoenvironment of the continental margins and ocean crust. Although some of the information gathered as a result of OMDP will contribute to developing the geologic framework upon which future exploration for oil and gas might be based, OMDP is not to be construed in any way as a resource assessment project.

NSF will begin the initial planning phase of this project in 1981; it will lead ultimately to deep penetration drilling. An 18-month effort will be required to complete all plans and designs leading to a go/no-go decision for phase II. Phase II would begin in 1982 and includes the conversion of the ship *Glomar Explorer* to a deep-ocean drill ship and the design and procurement of the advanced





Modifying for deep drilling. As shown in the drawing (right), after conversion to a deep ocean drilling ship, the *Glomar Explorer* (left) will be equipped to operate in 13,200 feet of water, penetrating up to 20,000 feet into the seafloor. These large capacities will permit exploration of continental breakup, ocean basis and crust formation, tectonic processes in deep ocean trench regions, and ocean margin histories.

drilling system using a 13,000-foot riser and well-control equipment. Actual drilling operations are scheduled to begin in 1984. Drilling would be preceded, accompanied, and followed by comprehensive science programs.

Work in 1980 reviewed the OMD platform feasibility studies conducted between 1975 and 1979. The current technical study defines performance requirements of the platform and drilling systems in enough detail so that a valid cost estimate can be developed. This requires resolution of major technical risks identified in the feasibility studies, trade-off evaluations, and selection of major systems.

An innovative agreement has been reached with the oil industry that provides for NSF and the participating companies to share in planning and financing the first phase of the project. Ten oil companies are already participating, and NSF is pursuing additional industry support. Continuation of joint funding is expected to be a requirement for subsequent activities.

Participation by foreign countries in OMD, as in IPOD, will be fully explored. The present IPOD countries participated in the planning that led to OMD. In addition, Canada and Mexico have also been invited to participate.

Ocean Sciences

During 1980 dramatic changes occurred in the legal status of the ocean and in our understanding of major processes operating on the seafloor. Both have increased opportunities and demands for ocean sciences. The Law of the Sea Conference completed its work and expects to finish a treaty in 1981 transforming about one-third of the ocean from a resource now freely available to all to a resource under the control of coastal states. For oceanographers this limits the unrestricted access that they have enjoyed and will hinder ocean science research done in distant waters. For U.S. oceanographers, it greatly increases the demands on ocean science. The United States now has responsibility for an ocean area about 80 percent the size of the Nation's land area. This area contains about 10 percent of the world's fisheries and unknown quantities of oil and gas. However, it is an area where we lack the detailed knowledge to iden-

tify and protect these resources or to develop public policies to maintain desired environmental quality.

Advances in our understanding of the important role of hydrothermal vents continues to alter our view of basic ocean processes. Earlier work showed that the composition of major salts dissolved in seawater is controlled by chemical reactions between circulating seawater and hot, recently formed oceanic crust. Work reported during 1980 has improved our understanding of the role of this deep circulation in the oceanic crust in cooling the sea floor and shows that these vents must be short-lived, ephemeral events to account for the very large heat flows of the spectacular "black smokers" observed from the research submersible *Alvin*. Future work will continue study of these features in areas where seafloor spreading is more rapid, and the effects are expected to be even more dramatic.

NSF supports about half of the ocean science research done in the United States and funds a comparable amount of the oceanographic facilities necessary to conduct that research. Virtually all the NSF-supported research is conducted at academic institutions, primarily colleges and universities.

During 1980 the International Decade of Ocean Exploration ended, although several of the projects begun under IDOE will continue to their scheduled completion dates in the early 1980s. The large-scale, integrated research activities that characterized the Decade will continue to be supported through the normal research-supporting mechanisms in competition with projects of all sizes.

Feeding Mechanisms in Zooplankton

Life for minute floating marine animals is dramatically different from that on land. On land, organisms are concentrated near or on the Earth's surface, making it relatively simple for animals to find enough food to survive. In the ocean, however, a vast amount and diversity of living material occurs in relatively dilute suspension in the tremendous volume of the oceans. Survival in pelagic (open ocean) ecosystems thus demands some mechanism for extracting food from water without the expenditure of too much energy.

Previously held views of how certain small filter-feeding animals obtained sufficient food for survival have seemed to be inadequate because they predicted that more energy would be spent filtering than would be obtained by feeding. This problem has been resolved by Gustav A. Paffenhofer of Skidaway Institute of Oceanography in collaboration with Miguel Alcaraz of the Instituto de Investigationes Pesqueras, Spain, and J. Rudi Strickler of the Australian Institute of Marine Science.

High-speed movie films of live specimens feeding in a normal manner revealed that copepods, one of the most important groups of animals in the pelagic ecosystem, are more efficient at extracting food from large volumes of water than had been previously imagined. The unexpected efficiency is obtained by taking advantage of the physical behavior of small amounts of water.

Copepods have specialized limbs behind the mouth. Some of these appendages are comb-like, containing a row of long bristles. It has long been held that these combs sweep through the water and catch algal cells between the bristles. Other specialized limbs aided the sieving activity by directing water currents and passing cells to the mouth. The difficulty was that the volume swept by the small combs was too small to feed the copepod if estimates of natural food concentrations were accurate.

From the high-speed films it was easy to see that the copepods did not simply filter with the comb-like appendages. Their small size (generally around a millimeter long) makes this energetically impractical. At such small sizes it would require considerable energy to force the narrowly spaced bristles through the water, because of its viscosity. But films reveal that food capture is an active rather than a passive process and that the feeding appendages form a complex, efficient food-capturing mechanism. The animal maintains a water flow past its feeding appendages by using them like paddles. When it detects an algal cell in the water—probably through some combination of chemical and physical clues—the movements change to bring the alga within reach of a feeding appendage, which then plucks it from the water and moves it to the mouth either alone or aided by other appendages. Thus, rather than being passive sieves, the feeding appendages serve as paddles to maintain a feeding current, pitchforks to shovel water out of the way and bring the food-bearing water close to the animal, sieves to catch the alga, and handling organs (setae) which work like chopsticks to manipulate the alga. The setae also are covered with sense organs which presumably detect chemical substances leaking from algae or changes in the flow pattern of the water caused by the presence of a particle. These observations show that an important link in marine food chains functions at a higher than anticipated efficiency.

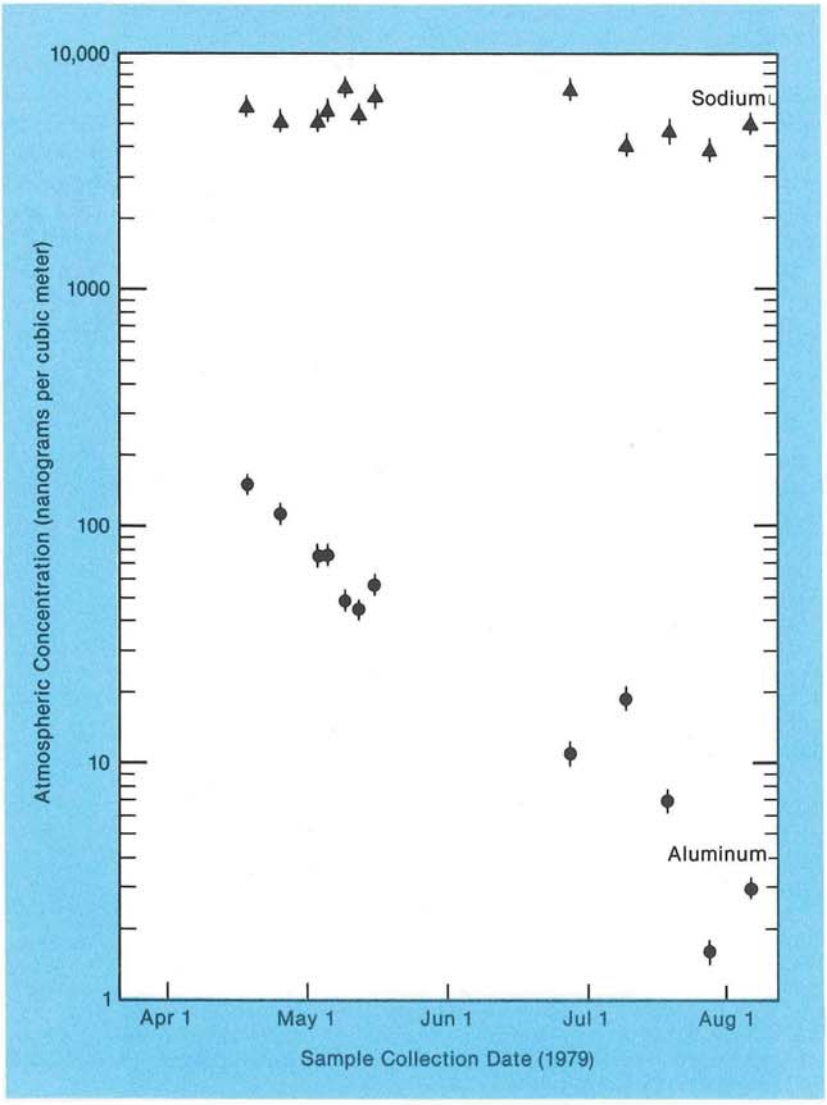
Of all the marine ecosystems, the pelagic realm is most alien. It has been studied for 200 years by sieving the animals from the sea with nets and then looking carefully at the dead organisms collected. Limited by the traditional methods of oceanographic observation, scientists have been hampered in observing natural or reasonably natural phenomena in pelagic ecosystems. The work of Paffenhofer and his colleagues shows the results of an examination of an

animal-environment interaction on the appropriate natural scales.

Asian Dust in the Open Ocean

The details of the interface between the atmosphere and the ocean change continually and challenge marine scientists trying to track particles both into and out of the ocean. Determining the source and amount of materials transported to the ocean requires a careful assessment of particle movement through the atmosphere from volcanoes, forest fires, wind storms, and sea sprays. Such an effort has been under way by the Sea-Air Exchange (SEAREX) project since October 1977. A major focus of this project is to collect and identify particles falling to the ocean and to adjust these measurements to account for material passed back into the atmosphere by sea spray. Materials are collected on towers, 20 meters high, which automatically collect samples only when the wind blows from a predetermined sector. Additional samples are collected by aircraft.

Studies during the first two years at Eniwetok, a coral atoll 12 degrees north of the equator in the Pacific Ocean, revealed a major input to the ocean of Asian dust never observed



Long-range transport. On a remote atoll in the western Pacific, this tower collects wind-borne particles falling into the ocean from predetermined directions. Results from the tower recorded the subsidence of an Asian dust storm through the 100-fold decline from April to August 1979 in aluminum-containing dust. For comparison, the concentration of sodium, which is derived from sea spray that is always present, remains constant.

before in this remote area. The hundred-fold decrease in aluminum content of trapped dust over a four-month time period indicates the subsidence of an Asian wind storm that carried dust containing aluminum to the equatorial ocean. SEAREX has now initiated a program to collect this material over a wide network in the Pacific with the cooperation of a Japanese university. Since sampling traps are expected to pick up sea spray at a constant rate, sodium measurements will be made to correct for the addition of sea salts.

Other metals and organic pollutants have been studied to provide information on the source of airborne materials. Iron, for example, was measured in Bermuda and showed that some air masses came from the United States and some came from the Sahara Desert. Both stable and isotopic lead is measured to learn their cycling characteristics and thereby generate models for other metal contaminants entering the ocean. Likewise, carbon from terrestrial sources has been identified, so the source of natural organic fluxes can be identified. Knowing the relative amounts of metals and organics carried by particles, researchers can develop better models of scavenging efficiencies and pollutant fluxes.

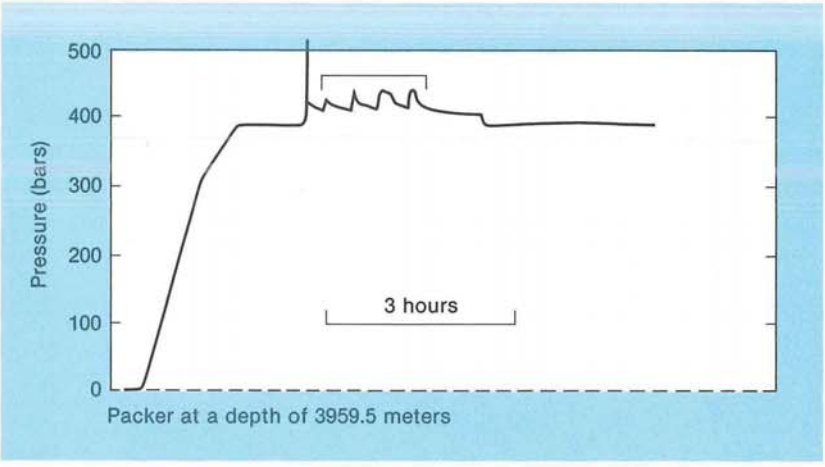
Measurements completed at Eniwetok are the first of a two-pronged attack on either side of the equator. This remote location in the mid-Pacific provides baseline samples in both the north and south trade wind air masses, where industrial pollution is minimal. Studies beginning in the Southern Hemisphere at American Samoa are expected to reveal concentrations an order of magnitude lower than at Eniwetok, since this air mass is separated from the heavily industrialized Northern Hemisphere by an effective curtain of convective air movement at the equator. A final phase of the SEAREX project will be conducted in the temperate zone near land where higher levels of contamination can be related to known sources; these should lead to better estimates of worldwide atmospheric pollutant transports to the ocean.

Hydrothermal Circulation of Midocean Ridges

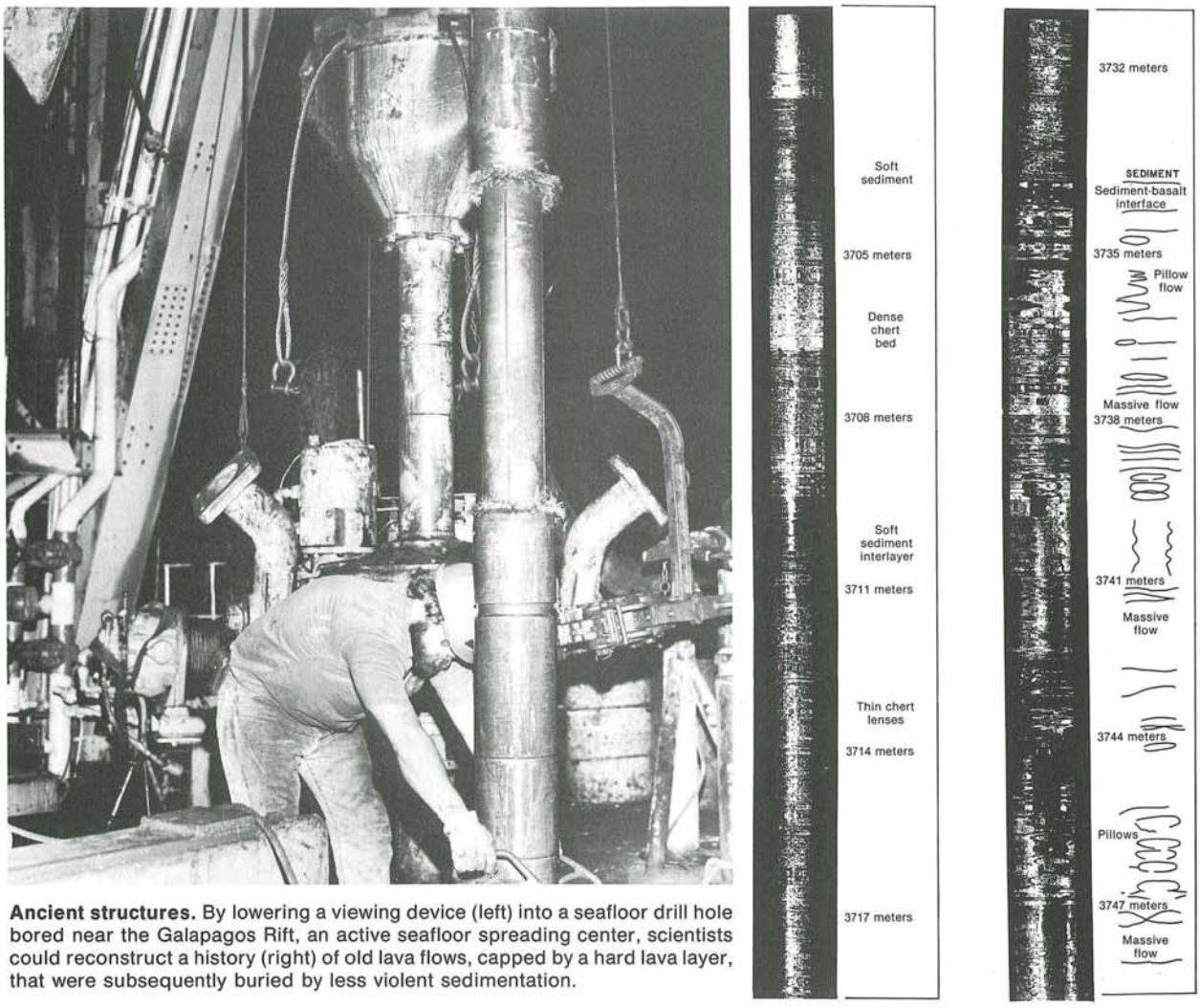
Convection of seawater through the hot, newly formed oceanic crust at midocean ridges is a recent but now well established physical phenomenon. Submarine hot springs or hydrothermal vents were first observed from submersibles at the Galapagos Rift in 1977. Later, active hydrothermal circulation was found at three additional locations along the East Pacific Rise off Mexico. These include a spectacular set of "black smokers" and "chimneys" just south of Baja California. As seawater circulates through newly formed oceanic crust, it removes heat and reacts chemically with the rocks. Metal sulfides are deposited around the vents as the hot fluids react with overlying waters. The vent fields also sustain unique biological communities whose food supply is dependent on the geothermal energy released by the vent systems.

To understand hydrothermal convection at the rise axis and the mechanisms that seal the systems on the rise flanks, the permeability of the crust to transmit fluids must be determined. Convective fluid movement deep within the oceanic crust continues for a significant distance from the rise crest axis and is a principal means of cooling the crust.

Crustal permeability was first measured in legs 68 and 69 of the International Phase of Ocean Drilling. Roger Anderson of Lamont-Doherty Geological Observatory of Columbia University and Mark Zoback of the U.S. Geological Survey measured flow rates, determined fracture patterns, and sampled formation fluids. A hydraulic formation packer was lowered into a drill hole near the Galapagos Rift and used to isolate a section of the well. A high



Pressure test. In the Galapagos Rift area, the permeability of buried seafloor rock was measured by pumping water under pressure into a drill hole, then recording the decay in pressure (each "sawtooth" records a repeat measurement, where pressure is sharply increased). The data show that the upper crustal rocks are fairly permeable, permitting circulation of hot solutions through them. Surprisingly, below that depth it was impossible to increase the pressure because the test water flowed into a deep, porous basalt zone opened up by the drill hole.



Ancient structures. By lowering a viewing device (left) into a seafloor drill hole bored near the Galapagos Rift, an active seafloor spreading center, scientists could reconstruct a history (right) of old lava flows, capped by a hard lava layer, that were subsequently buried by less violent sedimentation.

pressure pulse of water was then pumped into the hole. By measuring the rate which the pressure decays from the initial high value, they could calculate the permeability. A series of repeat measurements at different depths and pressures provided limits on the permeability range. They also used a borehole "televiewer"—actually an ultrahigh-frequency (1.3-MHz) acoustic probe—to get a "picture" of the walls of the drill hole in which they could identify and map solid rock, fractures, rubble zones, and lava flow contacts.

The results were surprising. The bulk permeability of the upper 210 meters of the oceanic crust is equivalent to the permeability of oil-formation-type sandstones from land. This permits strong convection cells to exist in this hot and young oceanic crust. However, the volcanic layer was apparently taking in water. The pressure at the bottom of the hole was less than would have been expected at that depth, and seawater actually flowed down the hole to fill a suddenly available reservoir system. The cause of this low-pressure zone is still not known. The borehole televiewer showed a large massive lava flow capping the highly permeable pillow basalt layers deeper in the section. This apparently acts as a very effective seal between the deep hot crust and overlying seawater. The act of drilling through the lava flow opened a channel through which bottom water poured.

Continuing research is examining the regional heat flow pattern, pore water fluid gradients in the sediments, and the regional geology. This work will define the extent and continuity of the low-pressure zone and its relation to crustal generation processes.

Organic Chemistry and Deep-Ocean Biology

Detailed studies of the chemical composition of organic matter in the ocean provides clues to how biological processes operate in the deep ocean. Organic matter in the ocean is originally derived from waste products or dead bodies of organisms. Once available, this material may be partially or completely degraded by other biota, structurally altered by physical/chemical processes, transported through the water column, and become incorporated intact into the sediment. To evaluate the relative contributions and specific diagenetic influence of these various processes on the oceanic organic carbon cycle, scientists have recently begun studying the transport and transformation reactions of specific organic compounds. Application of new instrumentation for analytical chemistry—such as high-resolution glass-capillary gas chromatography, mass spectrometry, and high-pressure liquid chromatography—to environmental problems has allowed marine organic chemists to isolate, separate, purify, and identify very low concentrations of individual organic compounds (e.g., picogram amounts) from complex mixtures produced in the biosphere.

Robert B. Gagosian and co-workers at the Woods Hole Oceanographic Institution studied compounds with "biological marker" information and used these compounds as tracers for processes affecting biogenic organic matter in general. They examined transport pathways and specific reactions and rates that molecules with specific functional groups undergo in seawater and sediments, and related these processes and reaction mechanisms to other organic compounds with similar functional groups.

Gagosian is concentrating on lipid class compounds, such as steroids. These compounds are key biochemicals in marine organisms from the point of view of energy storage and mobilization, reproduction, membrane structural components, and stimulation and regulation of metabolic process. Labile, or easily changed, organic compounds like lipids, rather than the more resistant forms of organic matter, take part in nutritional and chemical communication processes of marine organisms. Knowledge of the dynamics of these labile compounds is most important to our understanding of biological activity in the sea.

The Woods Hole group is describing the complex remineralization and transport processes that occur in the vertical movement of particulate organic matter to the ocean floor. Particles are collected in sediment traps deployed at various depths in the water column. Steroids act as tracers in these particle flux studies, which show the compositional changes in the particles as they fall through the ocean.

Results so far show that total organic carbon vertical fluxes in the deep ocean decrease only slightly from other depths. But significant alteration of organic compounds produced by plankton takes place as particles sink through the water. It is apparent from these studies that many organic compounds are consumed (i.e., recycled and/or remineralized) in the intermediate depths of the ocean. Only a small fraction (a few percent) of labile organic material associated with particles reaches the deep sea to provide food for organisms living on the deep ocean floor. It does in the form of large particles that sink at the relatively rapid rate of several tens of meters per day.

Oceanographic Facilities and Support

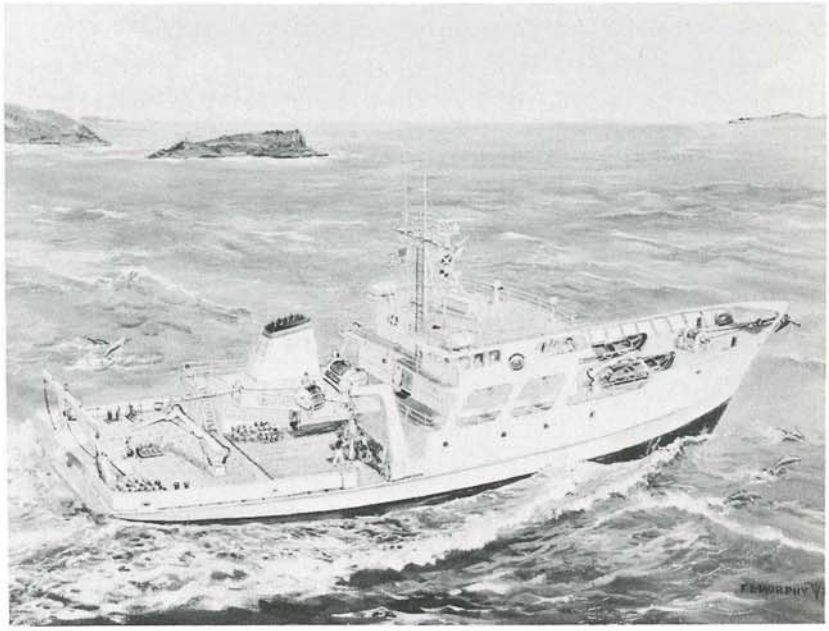
Research in ocean sciences requires a variety of well equipped ships as well as related shore support operations and facilities. Many institutions, academic and industrial, operate or charter research craft to fulfill temporary or limited requirements. But the heart of the academic research fleet serving Federally supported basic research is the 25 major ships concentrated at 16 member institutions of the University-National Oceanographic Laboratory System (UNOLS). NSF provides approximately 70 percent of the annual operating support for these ships.

Because of continued changes in scientific requirements and fiscal constraints over the past decade, this fleet of academic ships has been reduced in number and has evolved in composition to emphasize versatility and efficiency of operation. Significant progress has recently been achieved through the initiation of a long-planned construction program for coastal research ships. Two coastal zone research vessels (CZRVs), funded and owned by NSF, were under construction by June 1980 at Atlantic Marine, Inc., near Jacksonville, Florida. The CZRVs will be 135 feet long, powered by twin diesel engines producing 1,000 horsepower, and moving at a maximum speed of 12.5 knots. The ship design, by R. M. Matzer Associates, is the result of a five-year effort by UNOLS and NSF to plan a modern, cost-efficient ship specifically for coastal oceanography. These ships will provide a capability not previously available to seagoing scientists—ships with good seakeeping characteristics for year-round operations, with adequate working space and capacity for handling modern instruments, yet cost-effective for the frequent short cruises necessary for seasonal investigations of coastal processes.

Operation of these two ships has been assigned to the University of Miami and to a Duke University-University of North Carolina consortium under renewable five-year agreements. After delivery in late 1981 they will begin research operations in areas of the Gulf Coast and

the east coast of the United States.

In addition to surface ships and related support facilities, NSF continues to fund operations of the deep submergence vehicle *Alvin* and the tender vessel *Lulu*. The *Alvin/Lulu* system is owned by the U.S. Navy and operated by the Woods Hole Oceanographic Institution. Designated as a UNOLS National Facility, the system receives major funding from NSF, the Office of Naval Research, and the National Oceanic and Atmospheric Administration.



New design. Specifically intended to meet oceanographic research needs in coastal waters, two new vessels now under construction are scheduled to begin service in late 1981, replacing two older and more costly vessels.

United States Antarctic Research

Antarctica's ice-free areas total only about 2 percent of the continent, but a very important part. These small, scattered regions of bare rocks provide the only readily accessible areas useful to an understanding of Antarctica's geologic history, its potential for mineral resources, and its central role in continental drift.

The Ellsworth Mountains, a range containing Antarctica's tallest peaks, stand isolated between the mountainous Antarctic Peninsula and the Transantarctic Mountains, two long chains that form the spine of the continent. The Ellsworths, which occupy an area about the size and shape of Massachusetts, were seen from the air in 1935 and first visited in 1958.

Geologists studied some of the ice-free areas of these mountains in the early 1960s and quickly recognized that they could be a key to the geologic evolution of the entire continent. A problem was that the crustal unit comprising these mountains, known as the Ellsworth orogen, appeared to have turned crosswise to the neighboring older and younger zones; confirmation of this rotation was required if Ellsworth data were to be used meaningfully.

In December 1979 and January 1980, 42 scientists from eight countries examined the Ellsworth Mountains—the largest field party ever to visit the region. Using motor toboggans, helicopters, and airborne remote-sensing instruments, the investigators were able to study all of the significant areas that comprise parts of the 13,000-meter-thick stratigraphy. More than 70 oriented rock cores were drilled, and analysis yielded paleomagnetic data supporting the rotation of the Ellsworth orogen to a position crosswise to the east antarctic crustal block.

In the earlier Ellsworth work, fossil leaves of *Glossopteris*—a tree that flourished in all the southern continents during the Permian period 230 million years ago—were found. They provided strong evidence that Antarctica and the other continents once were joined. The area also had yielded one of the world's best assemblages of Cambrian trilobite fossils. During the 1979–1980 campaign, paleontologists collected numerous additional fossils for correlative, environmental, and evolutionary study and examined the evolution of landforms, beginning with a probable Jurassic uplift 160 million years ago. Based on this work, the stratigraphic record has been revised and refined.

Also during the field work, geologists mapped glacial erosion and deposition. Because the mountains are a barrier between the interior ice sheet and the coast, they record levels of the seaward expansion of grounded west antarctic ice. The study confirmed two phases of glacial history. First came alpine glaciation, with locally produced glaciers

Major field program. Transporting cargo to an outlying field camp, this helicopter was part of a support force that deployed and maintained 42 scientists and technicians in the Ellsworth Mountains in 1979-80. (U.S. Navy photo)

moving down the sides of the mountains. The second phase involved partial submergence of the Ellsworth Mountains by a west antarctic ice sheet that was 300 to 500 meters thicker than it is now. Decline to the present level took place about 10,000 years ago during the late Wisconsin, or about the same time the North American ice sheet was retreating at the end of the last ice age. In further support of this interpretation of the geologic history, an analysis of soil development and rock weathering suggested that most of the southern peaks were inundated by ice about 18,000 years ago.

Two surveys were interesting because of their negative findings: A radiometric survey from helicopters showed no significant concentrations of radioactive elements, and a search for meteorites in windswept areas of ice, extremely successful in other parts of Antarctica, turned up no specimens. Because of fine weather and smooth camp and aircraft operations, the field work was so productive that a previously planned return to the Ellsworth Mountains in the 1980–1981 austral summer was cancelled.

Solar telescope observations at the South Pole have dramatically confirmed the existence of solar global oscillations, or pulsations of the surface of the Sun, with a period of 5 minutes and have provided information about longer periods of oscillations as well. Preliminary analysis has suggested that solar oscillations with a period of 160 minutes may have been observed from the South Pole. While the 5-minute oscillations can be attributed to events in the outer layers of the sun, the 160-minute-period oscillations would have to originate deep within the Sun, upsetting the basic notion that the Sun's structure is neatly layered.

The South Pole was chosen as the observation site for several reasons. Most important, during the summer at the South Pole the Sun is visible for 24 hours a day at a constant elevation above the horizon, providing uninterrupted observing periods much longer than attainable anywhere else. The high elevation (3,000 meters) and the cold, dry air are additional advantages of the South Pole for solar observations.

These investigations were performed as part of the United States Antarctic Research Program, which each austral summer sends approximately 1000 scientists, technicians, and support personnel to study Antarctica's development, features, and processes.

Geological reconnaissance is aimed at understanding the geological history of Antarctica and its relationship to global dynamics; a related mapping program has resulted in nearly 100 topographic and geologic maps of much of Antarctica. Glaciological research is determining the dynamics of the ice masses and their relationship to changes in global climate. Biological and medical research is contributing to an understanding of terrestrial and freshwater ecosystems, the highly productive marine ecosystem, the special adaptations of organisms to the harsh environment, and the physiological responses of humans to the isolation and environmental stresses imposed in Antarctica. In the atmospheric sciences, investigations focus on the atmosphere over Antarctica and its relationship to global weather and climate, and on solar-terrestrial relationships. Oceanic research measures physical and chemical characteristics of water masses and their relationships with biological productivity and atmospheric circulation, and it is continuing geological and geophysical surveys around Antarctica.

The program is performed within the context of the Antarctic Treaty, which reserves the continent for

peaceful purposes, emphasizes scientific research, and freezes the territorial claims that have been made by seven nations. The objectives of the United States in Antarctica are to maintain the treaty, to ensure that the continent will continue to be used for peaceful purposes only, to foster cooperative research to solve regional and worldwide problems, and to ensure wise use of living and nonliving resources.

In support of this last objective, in May 1980 representatives of 15 nations including the United States completed negotiation, at Canberra, of a Convention on the Conservation of Antarctic Marine Living Resources. The convention is unique in that it provides for protection of the entire ecosystem; it also provides for a solid scientific basis in establishing prudent harvesting techniques and levels.

Arctic Research

Processes and Resources of the Bering Sea Shelf, a six-year marine ecosystem study, completed its fourth year in 1980. The major effort of this interdisciplinary study is to understand the processes that contribute to the production of enormous numbers of animals in secondary and higher trophic levels in the vast region of the sea extending over the outer continental shelf. Four percent of the total world marine catch comes from this area. In view of scheduled oil and gas exploration and development, the results of the study are expected to be valuable in providing an ecological basis for management of the resources of the region.

The project began with the hypothesis that oceanic features over the broad, shallow continental shelf combine with climatic events to favor high biological production. In 1978 shipboard observations documented that the study area is influenced by two different water masses, one originating over the shelf and one in the open southern Bering Sea. Differences exist in the plant and animal communities of each and in the timing of biological events.

These observations and other field work since that time have resulted in the discovery of a complex system of three oceanic fronts and two interfront regions—the outer shelf zone and the midshelf zone—that persist in the two water masses. These fronts are more widely separated on the Bering Sea shelf than are similar ones on continental shelves elsewhere. This spatial peculiarity has made practicable the studies that are leading to an understanding of the ecological significance of fronts and of processes that promote high secondary productivity in coastal areas.

The research results to date have led to a revised hypothesis: In the outer shelf zone primary production is coupled directly to secondary production, resulting in efficient energy transfer to the pelagic (open sea) food chain. In the midshelf zone these processes are relatively uncoupled, which leads to a low energy transfer in the pelagic food chain but a high energy transfer to the bottom dwelling species, the most important recipients of primary production in the continental shelf ecosystem.

In the Greenland Ice Sheet Program in southern Greenland, scientists from Denmark, Switzerland, and the United States drilled and retrieved an ice core to a depth of 901 meters. The ice there is 2,200 meters thick and may be 100,000 years old at the bottom. Extensive analysis was performed on the core at the site, and samples were taken to home institutions for additional analyses of oxygen isotope ratios, chemistry, particle content, conductivity, and mechanical properties. This program is attempting to decipher the detailed record of past climates that exists in the ice sheet. The annual snowfall has left a record of temperature and precipitation for the past 100,000 years.

Other investigations in the Arctic resulted in discovery in Greenland of the earliest known organic molecules—3.8 billion years old—and in collection of meteorological and sea ice deformation data from 20 data buoys deployed over the Arctic Ocean.

Biological, Behavioral, and Social Sciences

3

The research fields included in NSF's programs in the Biological, Behavioral, and Social Sciences range literally from A to Z—anthropology to zoology. The intellectual scope of these diverse fields is immense, and their timespans range from the 3.5 billion years of the paleobiologist interested in the most primitive proven life forms to the milliseconds of the biophysicist interested in conduction of an electrical impulse along a nerve or the picoseconds of the photosynthetic response. The progress reported in the following pages illustrates only a sample of the many interrelationships across these fields of science.

For example, biochemists' study of sensory reception in bacteria has implications for the study by neuroscientists of the transduction of light within the vertebrate eye during vision. Psychobiologists have shown that animal communication has direct similarities to the study of human communication by sociologists, linguists, and psychologists. The anthropological study of complex, ancient social systems bears on the study of our contemporary society by geographers, economists, and other social scientists. And underlying virtually all subareas of biological and behavioral research over the past decade have been advances in biochemistry and genetics.

Many of the recent advances described in this report illustrate how basic research provides the enhanced knowledge necessary for new approaches to problems faced by contemporary society. These include, for example, biological control of insect pests, better nitrogen fixation in economic plants, genetic engineering of crops for disease resistance and increased yield, recombinant techniques to increase the yields of needed substances such as insulin, and improved approaches to education through a better understanding of the cognitive capacities of young children.

The remarkable discoveries in molecular biology have profoundly influenced other areas of biological endeavor, such as plant science, ecology, and physiology, and have laid the groundwork for new insights into cells, tissues, whole organisms and their behavior, populations, communities, and larger systems. Molecular approaches have permitted dissection and understanding of smaller and smaller fundamental components of living cells, and the stage is now set for successful syntheses and reconstructive approaches in the 1980s. Results of new research to understand living systems will be even more rewarding in their dividends for society.

The effects of natural disasters are of particular research interest to many biological, behavioral, and social scientists, the Mount St. Helens volcano eruption being a case in point. The total support requested of NSF programs in Biological, Behavioral, and Social Sciences by the 80 appropriate proposals submitted fell just

Table 4*
Biological, Behavioral, and Social Sciences
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Physiology, Cellular, and Molecular Biology	1,275	$57.64	1,344	$62.29	1,487	$67.20
Environmental Biology	607	31.49	685	33.95	717	37.79
Behavioral and Neural Sciences	737	28.47	783	33.07	842	35.39
Social and Economic Science	419	24.25	460	25.39	518	26.64
Total	**3,038**	**141.85**	**3,272**	**154.70**	**3,564**	**167.02**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

short of one million dollars, and 31 grants were awarded at a total of $350,000. To capitalize on particular research opportunities, most of these proposals were reviewed and funded in less than two weeks from the time they were received by NSF.

The biological problems addressed were nearly equally divided among examination of effects of ash on biological processes in the soil substratum, on terrestrial vegetation, on terrestrial animals, and on streams and lakes. Projects concentrating on plants included studies of the ecophysiology, survival, and succession in both the forests of the impact zones and the grasslands of eastern Washington. An examination of Douglas fir bark beetles and woodborer populations in the impact zone may have considerable economic relevance. A study with interesting theoretic implication concerns pocket-gopher mounds in fallout areas as soil "islands," favorable sites for recolonizing plants. Behavioral and social science problems addressed included a study of the psychological impact of the eruption on affected residents, the effect of ashfall on the traditional economic resources and activities of native Americans, a study of the social impact of the eruption on the residents of eastern Washington, and a project examining media treatment of science during a natural disaster. More than half of the awards were made to Washington State University and the University of Washington; the remainder went to institutions in such other states as Arizona, Ohio, Montana, Utah, and Virginia.

The start of a new decade is a natural time for scientists to assess what has been accomplished and to project future prospects. In this first annual report of the 1980s, biological, behavioral, and social scientists can take great pride in their recent accomplishments and look forward to a more exciting research future than ever before. NSF anticipates these future discoveries with strong feelings of shared excitement.

Physiology, Cellular, and Molecular Biology

During the 1950s and 1960s the fundamental unit of living systems, the cell, was dissected into its subcellular and molecular components. The primary structures of the major classes of macromolecules were determined and, in many cases, confirmed by chemical or biological syntheses. Such knowledge permitted the function and interaction of parts of cells and of macromolecules to be investigated, and from these investigations metabolic pathways and their regulatory mechanisms were inferred. At that time, information transfer within the cell was described simply by what was known as the central dogma of molecular biology: Linear sequences of nucleotides in DNA, like so many beads on a string, were directly transcribed into RNA and then translated into amino acid sequences. The amino acids then hooked together to form proteins.

The early 1970s marked a transition to a reconstructive phase in molecular biology. Questions were beginning to be asked how subcellular and molecular components function and interact within the heterogeneous milieu of the cell itself, not just in the easier-to-study homogeneous isolation media. These questions were concerned with the molecular architecture of the cell and how and where, in the living cell, metabolism and information transfer take place. The concept of information transfer itself was being extended from the simple dogma of earlier decades to include the transfer of information from the cell surface to the cell interior, as well as transfer of information between cells.

During the 1970s several technological advances gave impetus to this reconstructive phase of molecular biology. High-voltage electron microscopy, for example, revealed far more complexity in the basic matrix of the cell than had theretofore been thought to exist. High-field nuclear magnetic resonance instrumentation was used in some cases to determine actual concentrations of metabolites within cells and even cell organelles (structures within cells). This information, plus new information that began to emerge on how enzymes function *in situ*, now indicates that old concepts about the regulation of cellular metabolism may have to be altered. Video capture, storage, and retrieval equipment used in conjunction with high-resolution electron microscopy makes possible the three-dimensional reconstruction of the structure of the cell at a near-molecular level. Video intensification equipment reveals how signal molecules such as hormones are first bound to the cell surface and then pass into the interior of the cell. Computer graphic imaging of data obtained from X-ray and neutron scattering and X-ray absorption by macromolecules advances our understanding of how molecules, including those in the cell membrane, interact and function. Equally important to advances in measurement capabilities have been advances in microprocessor control of the instruments. This makes it possible for nonspecialists to use highly sophisticated instruments as adjunct techniques in their research.

The 1970s also brought major advances in biological techniques. The

first successful cloning of a gene occurred in 1973. Refinements of this and related techniques have given rise to new and exciting concepts about the structure, function, and regulation of the genetic material. Genes, once thought to be consecutive sequences of nucleotides in DNA, are now known to contain intervening sequences that are not contained in the gene product. The information in these "introns" is eliminated during information transfer, perhaps during the processing of the messenger RNA that is transcribed from DNA. Genes were also once thought to be fixed in place on the chromosome—but certain genes are now known to move from one site to another. Experimental gene transfer techniques have recently been developed that allow the transfer of eukaryotic genes (those from cells with nuclei, as opposed to more primitive cells) into both plant and mammalian cells. This represents a major advance in our ability to do genetic engineering, and makes possible in principle the transfer of desirable genes from one species to another.

Another important advance in the 1970s was the development of the hybridoma technique to produce highly specific antigens. These antigens can be used to probe membrane structure, and this approach has begun to reveal the significance of surface recognition molecules in the cell-cell interactions that occur during embryonic differentiation. The identification of circulating cell growth factors and the use of these factors in conjunction with appropriate hormones and growth conditions have given rise to new approaches to cell culture that allow for the actual reconstruction of functional tissues from cells in culture. Thus the reconstructive phase in molecular biology, which empasized subcellular and molecular components in the early 1970s, is now beginning to address questions at the cellular and tissue level. As is always the case in science, advances answer some questions, but also raise exciting new ones. Answers to these await the molecular biology of the 1980s.

Insect Physiology and Pest Control

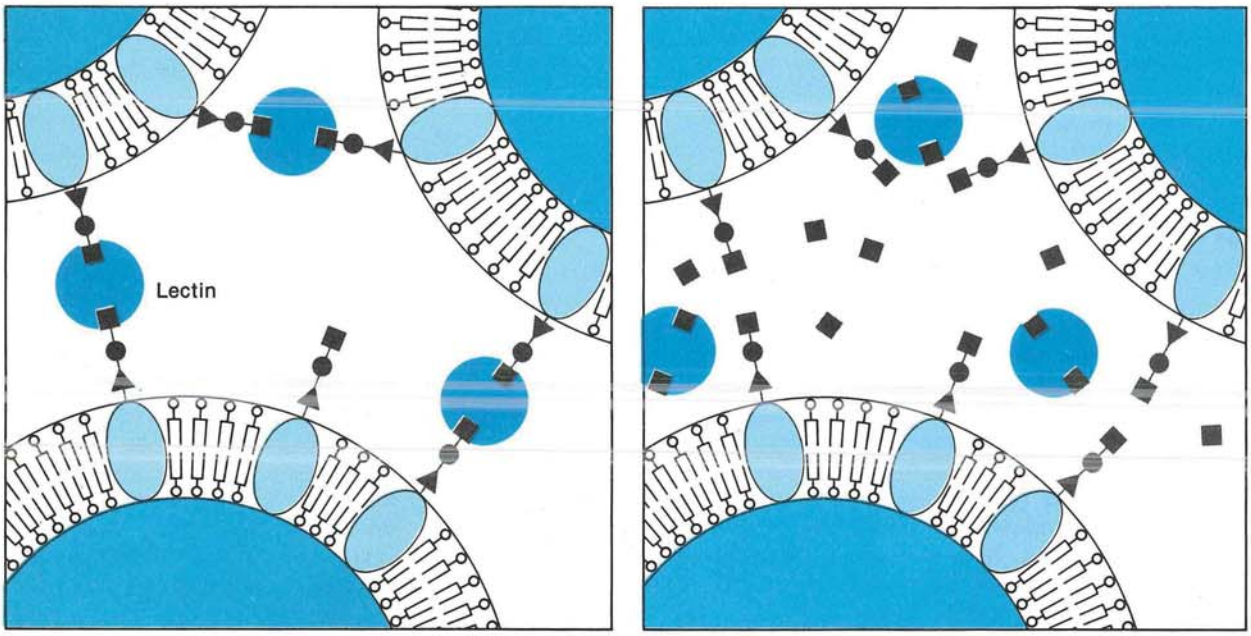
Basic research in insect physiology, endocrinology, and behavior is leading to new opportunities for the control of insects harmful to health and crops. These arise from the application of antihormones or analogs of natural hormones to disrupt such critical events in the life cycle as molting, maturation, or fertility. The value of such biological control becomes apparent when one considers that these substances are reasonably selective, not toxic to vertebrates, and nonpersistent in the environment.

Certain insect hormones—juvenile hormones—must be present throughout virtually all life stages. These hormones regulate the vital functions of growth, development, reproduction, sex attraction, diapause, and behavior. William S. Bowers and David M. Soderlund of Cornell University reasoned that, since insects and plants evolved together, among the secondary chemical substances developed by plants may be some that deter insect herbivores. In fact, just such juvenile hormone antagonists, called *precocenes*, were isolated from common bedding plants. These compounds were found to possess antijuvenile hormone activity and to induce precocious, or early, metamorphosis (thus the name precocenes) in immature insects. In addition, this can sterilize adults and stop sex attractant production. Although their level of potency is low and the number of species affected too restricted to permit economic use of precocenes as control agents, studies are now under way to develop more potent chemical analogs of these specific hormone antagonists for use against key agricultural pests.

An insect's juvenile hormone can itself be used as the basis for biological control in that these substances prevent metamorphosis and disrupt embryonic development. Less than eight years after the discovery of the chemical structure of juvenile hormone by Herbert A. Roller, now at Texas A&M University, the Environmental Protection Agency issued full registrations to the Zoecon Corporation for the use of "Methoprene." This synthetically produced juvenile hormone analog will be used as a floodwater mosquito larvicide and for control of horn flies in cattle manure. David Schooley of Zoecon recently discovered that there are four chemically different juvenile hormones. The number, combination, and concentrations of these four basic hormones are different in each insect species. More effective pest control should result from clarifying the unique juvenile hormone profile in each insect species, because selective inhibitors of juvenile hormone biosynthesis can now be developed that act like the precocenes.

Both bacterial and viral pathogens affect insects; they, too, may ultimately prove useful in biological control. For example, the bacterial strain *Bacillus sphaericus* 1593 infects mosquito larvae, producing lethal toxins. Although progress has been made toward industrial production and field testing of this bacterium in mosquito control, little is known regarding the toxin that causes larval death. Elizabeth Davidson of Arizona State University is currently purifying and characterizing this toxin in order to develop more stable commercial preparations.

Leon Rosen of the University of Hawaii has found that carbon dioxide, usually an innocuous narcotic for insects, kills mosquitoes that have become infected with certain viruses. A similar toxicity was originally observed in fruit flies harboring a he-



Cellular glue. Lectins, a kind of common protein, can bind to sugar molecules (shown as squares) protruding from cell surfaces, thus causing the cells to agglutinize (left). But if those same sugar "ends" are present separately in the cell suspension, they will then bind to the lectins, preventing the lectins from attaching to the cells (right). Lectins seem to be important in cell recognition functions such as symbiont and host-parasite recognition.

reditary virus, but it was considered unique to fruit flies. The possibility now exists that mosquitoes carry similar hereditary viruses that affect the viability of this pest under certain environmental conditions.

These examples are illustrative of the opportunities for biological control of insect pests that are emerging from far-ranging basic research in insect physiology, endocrinology, and behaviors. The intrinsic advantages of such approaches, including their selectivity, nonpersistence, and lack of toxicity for nontarget organisms, make biological control of insect pests an especially attractive alternative to pesticides.

Cell Recognition Molecules: The Lectins

Lectins, a class of proteins isolated from a wide variety of both plants and animals, seem to play a key role in cell recognition, though their mechanism of action is still not fully understood.

It is believed that lectins facilitate cell adhesion by binding to sugar molecules that extend from cell surfaces, in a fashion similar to the binding of antibodies to antigens. Cell surface membranes contain lipids (fats) and proteins with branching chains of sugars. When lectins, which have multiple combining sites, bind to these sugars, cross-links are established and cause cells to agglutinate or to adhere. This reaction is reversible by adding to the system those sugars responsible for the binding; they occupy the lectin binding sites, thus preventing or reversing agglutination. Since the agglutination response is selective, lectins that bind to particular sugars can be used to map the surface of cells.

The first lectin, ricin, was isolated in 1888 from castor bean seeds (*Ricinus communis*) and received attention mainly because of its ability to clump or agglutinate red blood cells. It gradually has become clear that lectins permit plants to recognize and distinguish between potential pathogens and potential symbionts and thus play an important role in nitrogen fixation and pathogen recognition.

Symbiotic associations between leguminous plants and bacteria of the genus *Rhizobium* provide most of the biologically fixed nitrogen available for agriculture. But a high degree of host specificity is involved: *Rhizobia* will infect and nodulate only roots of its complementary species. This may occur when specific legume lectins bind to complementary carbohydrates found on the surface of the appropriate rhizobial symbiont. Frank Dazzo and his associates at Michigan State University are testing this hypothesis in the symbiotic sys-

tem of *Rhizobium trifolii* and clover root hair. Dazzo has found the lectin involved—trifoliin—in clover seeds and seedling roots. He and his associates think that an early recognition event occurs on clover root hair surfaces prior to infection. The lectin recognizes saccharide residues on the bacterium and clover and cross-links them in a complementary fashion; this initiates the preferential and specific adhesion of the bacteria to the root hair surface. Since the surface carbohydrates are antigenic, Dazzo is using immunological techniques to identify structural relatedness of the antigens. A similar symbiotic system—that of *Rhizobium japonicum* and soybean—is being studied by Wolfgang Bauer and his associates at the Charles F. Kettering Foundation in Yellow Springs, Ohio. They have found that soybean lectin binds the receptors on the surface of *R. japonicum* and that the binding is fully reversible in the presence of appropriate sugars. They have found, however, that there is a high degree of binding variability with age. If the lectin receptors are transient components of the bacterial cell surface, then the developmental stage of the symbiont and probably also of the host plant cells may be important.

Lectins also play an important role in pathogen recognition, because acceptance or rejection of bacterial pathogens seems to depend on the interaction of bacterial sugars and cell wall components of the host. It is thought that extracellular sugars of the outer cell wall of pathogenic bacteria bind to complementary polysaccharides and lectins of the host plant cell wall. The best demonstration of this has been provided by Luis Sequeira and associates of the University of Wisconsin. They found that lectin isolated from potato tubers binds to and agglutinates nonvirulent variants of *Pseudomonas solanacearum*, a bacterial pathogen of potato and tobacco, but not to virulent strains. These workers found that nonvirulent strains of *P. solanacearum* were rapidly agglutinated when injected into potato or tobacco leaf tissue. Virulent strains were not agglutinated. Thus, it may be that virulent strains have evolved a mechanism to avoid detection by the host plant.

In summary, accumulating evidence in many plant systems implicates lectins in cell recognition. However, there are still many basic and important questions to be resolved, and research interest in lectins is increasing rapidly.

Protein Location in Cells

The bacterium *Escherichia coli* has been widely used to solve fundamental problems in molecular genetics, and scientists' ability to manipulate this bacterium genetically has provided an understanding of how proteins find their ultimate locations within cells. *E. coli*, like other gram-negative bacteria, is surrounded by two membranes—an inner, cytoplasmic membrane, and an outer membrane. Proteins are found imbedded within these membranes and in the periplasmic space between the two membranes. These periplasmic proteins play a role in the transport of nutrients into cells and in the hydrolysis (decomposition) of nutrients. (If these enzymic proteins were localized in the cell cytoplasm, they would damage the cell components.)

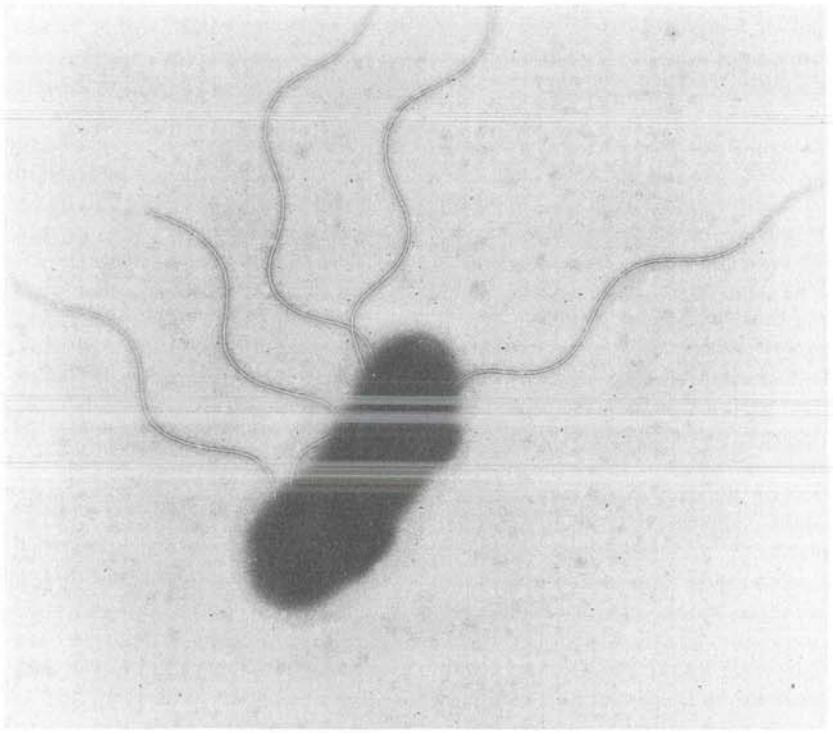
Jonathan Beckwith of Harvard Medical School has been studying the synthesis and ultimate location of proteins involved in the transport of a sugar, maltose, into bacterial cells. This transport system involves proteins found both in the inner and outer membranes and in the periplasmic space. Several years ago it was found in higher organisms that proteins secreted through cell membranes were synthesized first as longer precursor molecules that were then cleaved during secretion. It was postulated that an amino acid sequence at one end of the precursor protein—the signal sequence—binds to the membranes and, further, that this signal sequence of about 15 to 30 amino acids was removed during transport through the membrane. The sequences of the postulated signal vary from protein to protein, but a common feature of all signal sequences was found to be a central core of roughly 10 to 15 predominantly uncharged hydrophobic amino acids—a finding consistent with their nature as the membrane signals.

In an ingenious series of experiments Beckwith and his colleagues showed that transport of the newly synthesized proteins to the correct location in the cell required the signal sequence. They used a series of genetic manipulations to fuse the gene for beta-galactosidase, an enzyme normally found only in the cell cytoplasm, with portions of genes coding for proteins found in other cellular locations. They found that if the hybrid protein contained a sufficiently long segment of the amino-sequence end of a membrane protein, it was transported to the appropriate membrane.

Later, drawing on years of experience with the genetics of the beta-galactosidase enzyme, they were able to isolate mutants of those hybrid genes that accumulated, rather than transported, the hybrid proteins in the cell cytoplasm. The mutations have been mapped to the portion of the gene coding for the signal sequence of the proteins. With Maurice Hofnung of the Institute Pasteur, a collaboration supported by the NSF, the group determined the coding sequences of the DNA of the mutant genes. From these sequences the amino acid sequences of the altered proteins can be deduced. In almost all cases the alteration is such that one of the hydrophobic amino acids in the signal sequence has been replaced by a charged amino acid, pro-

viding the best evidence to date for the signal sequence hypothesis.

This dawning ability to manipulate the locations of proteins in cells by attachment of the appropriate portions of different genes is a triumph of molecular biology—with many practical implications. One early example: The yield of insulin produced in recombinant bacteria carrying the animal gene for insulin can be increased if the insulin gene is fused with the beginning of a gene for an *E. coli* periplasmic enzyme. The resulting protein is secreted and can then be easily recovered and cleaved to yield the pure hormone.



Propulsion/steering system. Bacteria, such as this *E. coli*, respond to stimuli by rotation of these long flagella. The direction of rotation results in either random or straight-line movement of the bacterium and is a sensitive response to chemical signals in its local environment.

Sensory Reception and Motility in Bacteria

The capacity to sense and react to stimuli is a characteristic trait of all living organisms, from the largest mammals to the smallest bacteria. Bacteria sense a variety of stimuli, including heat, light, magnetism, and many different chemicals. The most common bacterial response is motility, either swimming away from (aversion) or toward (attraction) the stimulus. Studies to determine how bacteria process stimuli and direct their motile behavior have revealed a surprisingly complex picture of the underlying biochemical events and are serving as a useful model system for sensory and neural phenomena in higher-level organisms.

The motility of bacteria is due to the rotation of long sinuous flagella which act essentially as propellers. Julius Adler of the University of Wisconsin has observed that flagellar rotation may be either clockwise or counterclockwise; counterclockwise rotation leads to long straight runs, whereas clockwise rotation results in "tumbling" movement which tends to randomize direction. In response to a chemical gradient (a constant, directional increase or decrease in intensity) of an attractant, bacteria oriented in an "up-gradient" direction will respond with long straight runs, whereas those oriented across the gradient and "down-gradient" will tumble and perform short runs until the direction favors a long run.

Adler has also shown that bacteria have specific sensory receptors which, when occupied by an appropriate molecule, control the rotation of the flagella. The essential steps of how the chemoreceptor exerts its control are now being clarified through genetic manipulation to dissect sensory reception and motility.

However, certain bacterial mutants don't respond to a number of attractants. Following a biochemical "hint" that methionine (a sulfur-containing amino acid) was in some way involved in the sensory processing, but not in motility itself, Adler observed that some of these mutants were defective in a particular biochemical step—the methylation of protein fraction. This protein class, the methyl-accepting chemotaxis protein (MCP), was subsequently simultaneously shown to be composed of at least two types, MCP I and MCP II. (Another, MCP III, is postulated on indirect evidence.)

It turns out that in normal bacteria, these MCPs are methylated in response to increasing level of attractants, resulting in counterclockwise flagellar rotation and long-run swimming; decreasing levels of attractants result in demethylation of the MCPs and tumbling. Robert McNab of Yale University and Daniel Koshland of the University of California, Berkeley, have shown that when bacteria are shifted from a constant low level of attractant to a higher level of the same attractant, there is a brief pe-

riod of long-run swimming, but this is followed by an "adaptation" to the higher level, and tumbling then recurs. Biochemically, Adler has shown that the long-run period reflects the time during which methylation of MCP is increasing. Once the rate of methylation has reached a higher plateau, long-run behavior is suppressed.

This adaptive behavior is a classical aspect of the sensory systems of all organisms, including humans, and represents a primitive form of "memory." In the bacterium's world it serves the specific function of bringing the bacterium up-gradient to the highest level of an attractant without overshooting the objective. Such a behavior is possible only with a "memory" of what prior concentrations of attractant have been. Indeed, bacteria that are defective in an MCP are characterized by nonfunctional long runs; they can't as readily adapt to an attractant and consistently overshoot. Such mutants emphasize the distinction between the excitation input, which is not clearly understood at present, and the adaptive output controlled by the methylation and demethylation of MCPs.

Research on sensory reception and motility in bacteria is providing an enticing glimpse into a complex, tightly integrated sensory model. Some answers and many intriguing questions are emerging from this work. For example, how do the chemoreceptor proteins cause excitation? Precisely how do the methyl-accepting proteins control rotational direction, and how does the flagellar-driving mechanism, the smallest known motor, work? What are the relationships between bacterial sensory reception and the sensory mechanisms of higher organisms? There seem to be significant parallels. Stimulated by the bacterial findings, researchers have begun to look for methylation of proteins in higher cells, and Julius Axelrod of the National Institutes of Health has recently discovered that mammalian white blood cells, which also have chemotactic responses, show an increase in methylation of protein fraction when responding to an attractant. Thus, key findings in bacteria about the role of protein methylation in sensory modulation may be an important key to the understanding of major unsolved biological mysteries such as sensory reception in more complex organisms, the mechanisms by which nerves respond to neurotransmitter chemicals, and how cells in development and differentiation migrate and reorient themselves in the growing organism.

Environmental Biology

A key to effective progress in environmental biology is to view the objects of our research as systems. An environmental or ecological system consists of a biological part interacting with an environmental part. Such systems include the global system, or ecosphere; large landscape systems, or biomes, such as tundra or tropical rain forest; and small-scale watersheds containing ecological communities, populations of plants and animals, and individual organisms. These systems can be arranged in a hierarchical pattern, with each unit containing within it smaller systems and being, in turn, part of a larger system. Hierarchical organization provides a framework for research on complex systems. Without such a framework, studies of individual systems may lack coherence and context. It is appropriate that NSF's programs in environmental biology reflect the natural hierarchy, with programs supporting research on biomes, communities, populations, and individuals.

NSF provides about 90 percent of the support for basic environmental biology research at colleges and universities. Basic research in environmental biology has direct connections to the substantial environmental problems of society, and it undergirds the applied research and actions of other agencies in solving such problems. Basic research becomes increasingly important as the various stresses on our environment increase.

The materials of interest to environmental biologists are exceptionally diverse. It is estimated that there are about 4.5 million species of plants and animals in the ecosphere. Each species is genetically distinct, represents a unique process of evolution and adaptation to a particular set of environmental conditions, and is worthy of individual study. These populations in turn make up a great variety of ecological communities. Environmental biologists have coped with this diversity of systems by using special techniques such as ecological modeling and by developing active theoretical efforts at all levels of biological organization.

The complexity of environmental systems has often required equally complex organization of research efforts. For example, large teams of research workers have concentrated their attention on a single ecosystem, such as a tropical rain forest or a prairie grassland, with impressive results. During 1980 NSF embarked on an effort to bring such ecological research better into line with both the temporal and spatial patterns in nature. This effort, termed long-term ecological research, involves series of ecosystem studies located at a variety of sites across the United States. To ensure comparability of results the

research teams use similar methods and concepts in their elucidation of organic production, decomposition, and turnover of essential nutrients. These studies will gradually expand and will be maintained over time so that the response of U.S. ecosystems to larger-scale changes in the environment can be determined. These data should permit more accurate assessment of the consequences of drought, volcanic eruption, and variation in global atmospheric carbon dioxide levels.

Environmental biology has also had a special interest in the study of tropical populations and communities. The majority of the 4.5 million biological species on Earth occur in the tropics, and many of these are threatened with extinction as tropical habitats are converted to other uses. NSF is the major supporter of U.S. basic research in tropical biology and thus has primary responsibility for supporting new efforts to understand this region. Although a great deal of research has been done in the tropics, our knowledge is still too limited for effective management of tropical lands and waters. Systematic biologists, who classify and name plants, animals, and microorganisms, have given names to only about one-sixth of the predicted tropical biota. The number of organisms known well from a biological and ecological viewpoint is even smaller, and our understanding of tropical ecosystems is limited to a few locations. Since there is a great deal to be done, the needs for information are great, and time is short. NSF is continuing to emphasize the study of tropical biology. The following study illustrates an integrated research effort in tropical biology.

Mayan Urbanization in Tropical Forest

As emphasized in *The Global 2000 Report to the President*, prepared in 1980, "[e]nvironmental, resource, and population stresses are intensifying and will increasingly determine the quality of human life on our planet." Although the scale of environmental degradation may never have been as extreme as it is today, environmental crises faced by earlier cultures had profound and lasting effects. Recent paleoecological investigations of the Mayan civilization, under the direction of Edward S. Deevey of the University of Florida, provide an illustrative example. Approximately 1,000 years ago, this civilization was flourishing in the biotically productive but fragile lowland tropical forest of northern Guatamala and then collapsed.

A principal objective of the research was to determine the strains imposed by Maya urbanization, from about 1500 B.C. to 1500 A.D., on the supporting ecological system that may have contributed to the collapse of the civilization. Organic remains of agricultural products do not survive well in humid tropical environments; the consequent paucity of evidence makes it difficult to reconstruct the patterns of land use and cultivation from about 3,000 years ago to recent times. Paleoecological techniques provide information on land use, but locating a study site with nearly ideal pollen-stratigraphic sections in sedimentary terrain, in this case Karst (porous limestone), was an essential step in this research.

In the context of the complete 8,000-year pollen record available for the site, the episode of deforestation and lacustrine (lake) siltation appears as a 2,500- to 3,000-year disruption in the domination of the record by tropical forest tree species. Pollen diagrams from lake-bottom cores show that human factors, rather than climatic fluctuations, were responsible for the incursion of species more typical of grasslands. Chemical analyses by atomic absorption reveal that influxes of sedimentary silicates and carbonates to lake waters were at concentrations 20 to 40 times higher during the more urbanized Classic Maya times than in deposits during Pre-Maya and Early Preclassic intervals. Soil analyses show phosphorous loading to lakes was not occurring simply by means of leaching, but primarily via colluviation, or downslope bulk transfer of soil, as a consequence of agricultural exploitation and urban spread.

Prior to the ninth century A.D. collapse of Classic Maya civilization, the population of this urban center is estimated to have exceeded 5 million within a 20,000-square-kilometer core region, having grown since the Late Preclassic (250 A.D.) clearing of forested areas; it grew at a rate of 0.17 percent annually, which means the doubling time would have been about 410 years, or 12 to 16 generations. This compares with a present-day annual growth rate of 0.7 percent in the United States, representing a doubling time of 99 years, and an average rate of 2.0 percent for less developed countries, a doubling time of 34 years. Population growth would have been imperceptibly slow to the Mayas. Environmental strain, a product of accelerating agricultural demand and the depletion of soil nutrients, probably also increased slowly and may have reached advanced stages before the dangers were perceived. By then the environmental damage may have become largely irreversible. In any case, the district has remained to this day largely uninhabited, owing to the long-term deterioration of soil quality.

Lingering questions remain: How early, if ever, did the Mayan rulers determine that their successive agricultural intensifications threatened the stability of their vulnerable ecological base? Would they in any case have been able to prevent or forestall the collapse? Indeed, these are ultimately the sorts of questions that necessarily must be faced by any technological society, including our own.

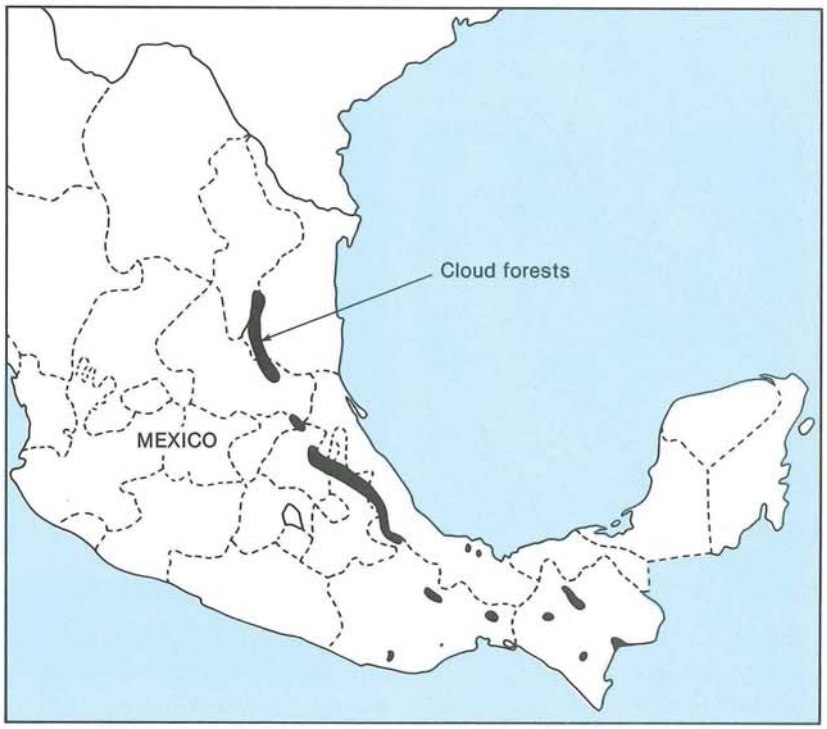
Genetic Diversity in Maize

Of the estimated 4.5 million kinds of organisms in the world, at least 3 million occur in the tropics—a region now under substantial environmental stress. A century and a half ago tropical forests comprised an area twice the size of Europe. As a consequence of human activities these forests have now been reduced to roughly half their former extent; reduction is continuing at an increasing rate. A report, *Research Priorities in Tropical Biology*, recently published by the National Academy of Sciences, indicates that there is high probability that more than half of the species of plants and animals now living in the world will be extinct by the year 2100. Obviously, some plants and animals become extinct naturally through normal interactions with other organisms and the environment. However, loss of half the products of 3.5 billion years of evolutionary history in only 120 years is a sobering possibility.

Survival, evolution, and natural selection depend on the amount of variability present in a population. In view of our own dependence on food plants and domesticated animals, such variability needs scrupulous protection. It is dangerous to depend on single strains of cultivated plants and, further, the source of new wild plants may also be important.

For example, Hugh Iltis of the University of Wisconsin recently discovered a primitive perennial wild relative of corn in a remote mountain area of Mexico. The area is a mid-altitude cloud forest, never a very common biotic community and one that is now becoming a rare and endangered habitat. The new plant (one of several species called teosinte by native Mexicans) occurs only in four localities in the Sierra of Manantlan in southwestern Mexico. It was perilously close to extinction before its discovery in 1978.

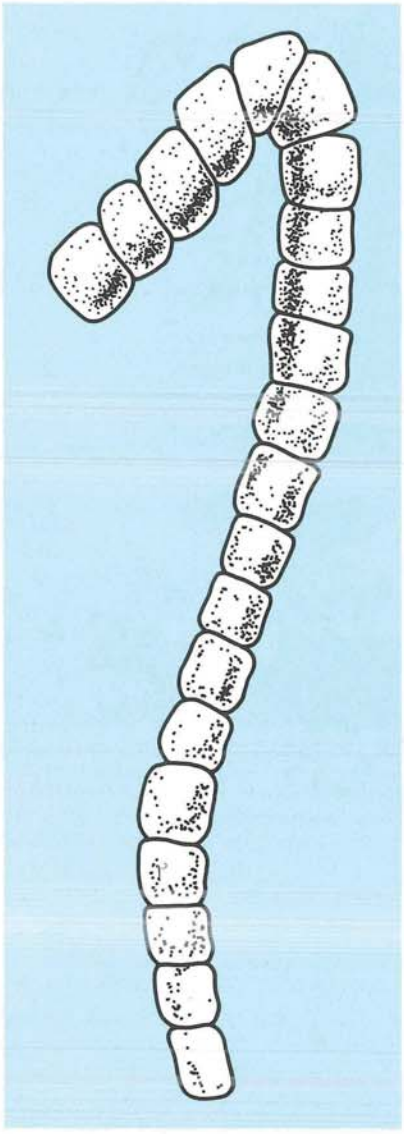
This teosinte has short, thick underground stems that allow it to reproduce without replanting. Its discovery is particularly significant because the plants have the same number of chromosomes as corn, with which it can be readily crossed. It is immune to several major corn virus diseases and is adapted to cool mountain climates. The new teosinte also may ultimately provide the genetic basis, through selective breeding, for a perennial corn that could be grown in the United States. If, through incorporation of genes for disease resistance, this plant could add only one percent to yield, it would increase the value of the United States corn crop each year by $150–200 million. Such a crop might also save energy in planting and cultivation and conserve the soil by its binding root system.



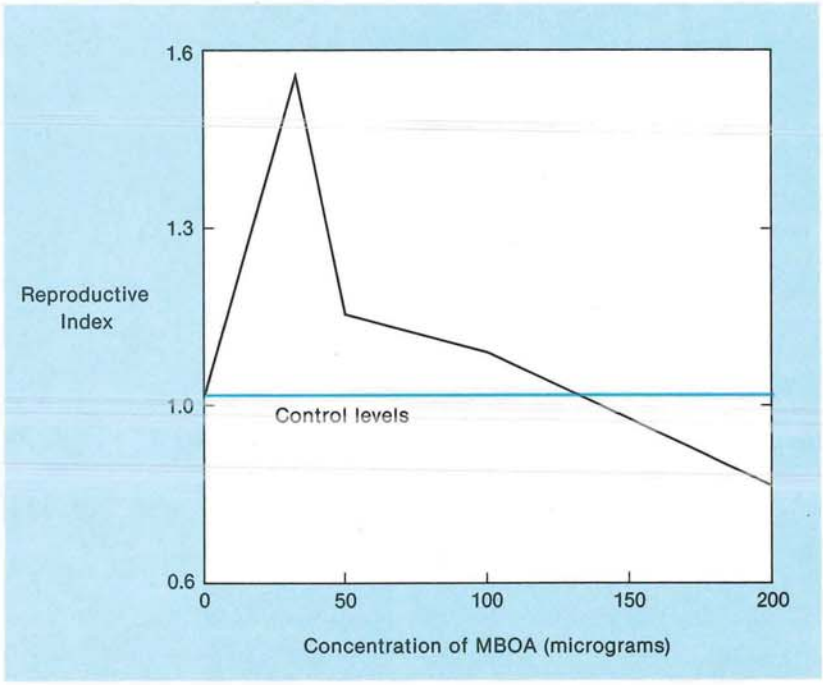
Teosinte. The rare cloud forests of Mexico, an endangered biological habitat, recently yielded an important wild species of primitive corn that could have impact on food crops and agricultural economics. By cross-breeding this disease-resistant variety with domestic plants, scientists may be able to develop a naturally healthy corn plant that is also perennial (needs no annual replanting) and can grow in cool climates. (Map after Pennington and Sarukhan)

New Windows to the Ancient Past

The oldest cellular fossils known have been discovered by scientists from the University of California, Los Angeles, and from Australia. Their findings prove that primitive forms of life existed as long as 3.5 billion years ago, 1.2 billion years earlier than the previous best documented records. According to J. William Schopf of UCLA, the tiny, threadlike fossils represent at least five types of microbial forms of life, some made up of chainlike groupings of distinct, minute cells. These bacteriumlike organisms, nearly three-quarters of the age of the Earth itself, lived in flourishing communities at the bottom of a shallow sea in what is now part of Western Aus-



Oldest fossils. This drawing depicts the remains of tiny chains of microbial cells found in Australian rocks deposited in a shallow sea 3.5 billion years ago. The discovery now substantially pushes back the origins of life forms on Earth to some time within the first billion years of its existence.



Natural population regulation. Field mice are affected by a chemical (MBOA) produced in varying amounts by plants they eat. Small concentrations typical of mature plants can increase mouse reproduction; large amounts, found in young plants, inhibit reproduction. Such findings may enable plant breeders to alter plant chemistry to reduce crop damage from mice.

tralia. Schopf, the 1977 recipient of NSF's Alan T. Waterman Award, heads a team of 15 scientists from several nations and many fields of study who have been assembled to investigate the origins and earliest history of life on Earth.

This new discovery of primitive life forms follows the earlier finding of distinctively layered rock structures known as "stromatolites" and represents the first direct evidence of fossil cells in these ancient rocks. The earlier stromatolites, while they implied the existence of life, did not contain cellular remnants of the microbes that apparently built them. Discovery of the fossils themselves is the paleobiologists' equivalent of finding the "smoking gun"—it gives clear-cut evidence not only of the existence of early life, but also of the types of organisms that were present.

Prior to the current discovery, the oldest completely accepted fossils were relatively complex life forms from southern Africa dating back "only" about 2.3 billion years. The newly discovered fossils have thus pushed back the record of cellular fossils by some 1.2 billion years and are more complex than might have been expected. They demonstrate that the surface of the Earth was habitable some 3.5 billion years ago and that it was populated by numerous types of relatively advanced, bacteriumlike forms of life. It is now evident that life originated even earlier, some time between the new date established by these oldest known cells and the formation of the Earth one billion years earlier.

Plant-Animal Feedback Systems

An intriguing and important aspect of ecological research involves reciprocal relationships between

plants and animals through herbivory. The study of plant consumption, the impact of animal herbivores on plants, and the utility of plant foods to animal growth and reproduction are common themes. Recently, ecologists have shown that the interrelations of plants and animals are characterized by a variety of subtle biochemical features that act in addition to the familiar nutritional and mass-action features of feeding.

Norman Negus of the University of Utah is evaluating the influence of the natural plant compound 6-methoxybenzoxazolinone (MBOA) on mammalian reproduction and growth. This estrogen-like material is manufactured by plants in different amounts at different times of the year. It reaches its highest concentration in young plants and declines as the plants reach maturity and flower. Negus has shown that as MBOA is consumed in small amounts by field mice, their reproductive cycle is affected, resulting in an increase in the number of young born. Larger amounts of MBOA cause a decrease in these reproductive factors. This finding is of particular interest because mice populations sometimes reach high levels (over 1,000 per acre) and cause substantial damage to pastures and orchards. These experiments suggest possible new ways of reducing crop damage caused by herbivores by altering the plant chemistry through plant breeding.

Several other research projects are assessing how various biochemicals regulate material transfer and thus provide the basis by which information is passed through highly aggregated systems. For example, growth regulators in the saliva and urine of grazing animals such as bison have been reported by Melvin Dyer of Colorado State University. He shows that the salivary components seem to regulate plant growth in much the same way that plants regulate mouse reproduction: Small amounts result in increased plant production, while larger amounts inhibit growth. This research illustrates that not only do plant substances regulate animal growth, but, conversely, animal substances can regulate plant growth. Understanding both kinds of interactions rests upon knowledge of sophisticated biochemical analyses and the ecology of plant-animal interrelationships.

Behavioral and Neural Sciences

Rapidly increasing capability to do research in the behavioral and neural sciences has accelerated the production of new knowledge of theoretical and practical importance. Technological developments based in part on advances in the chemical, physical, and engineering sciences have increased the rate at which important discoveries about the nervous system are being made and have heightened the excitement associated with the neurosciences. For example, recent research has shown that developing neurons are guided to appropriate connections by specific identifiable membrane components. Mitigating occasional wrong connections and assisting the regeneration of damaged nerves are now matters for which this line of research holds great promise. Neuroscience research is being stimulated, as well, by the recent demonstration that an individual neuron can communicate with other neurons by numerous chemical neurotransmitters. A new appreciation has also evolved about the relationships between excitable neurons and the presumed supportive glial cells; it suggests that glia participate as full partners with neurons to regulate the production of chemicals essential to neuron communication.

Other developments are having substantial impact on our knowledge of the sensory systems. Psychophysics is a powerful method relating two well defined conceptual domains: the properties of the stimulus (e.g., its wavelength and energy) and the resulting subjective experience that is expressed in overt behavior (e.g., detection of a stimulus or judgments of apparent brightness or loudness). In spatial vision, for example, psychophysics has challenged the earlier implication from physiological studies that the visual system functions as an array of specialized detectors (such as edge detectors) of the simple geometrical properties of the stimulus. Instead, psychophysical studies point to the spatial frequency content of a visual stimulus as one of several complex but critical stimulus dimensions. These studies have led to precise quantitative models to test new hypotheses about fundamental sensory mechanisms.

Another area of increased recent interest is animal communication. Much has been learned about how chemical signals, the pheromones, transmit information between individuals about such things as reproductive status, the location of individual and group territories, and even social position. Pheromones have been identified in many animal species, and there are indications that such chemicals may play a role in human and other primate social interactions. Auditory communication, too, is important and has recently been found to be much more specific than was previously thought. For example, the alarm call that a ground squirrel emits when a dog is approaching is different from its call when a badger is coming. Further-

more, the call varies as a function of the speed with which the threat approaches.

An essential aspect of cognitive science today is understanding how cognitive capacities develop. Such understanding will enhance approaches to educating very young children and allow anomalies to be detected early enough for intervention programs to be started. Great strides have been made in understanding the development of number concepts, logical relationships, reading and writing competence, language acquisition, and other cognitive capacities. While a great deal has now been learned about cognitive development in children as young as two or three, the recent development of new techniques, chiefly involving habituation and the duration of gaze at an object, now allows scientists to examine the development of these capacities in infants only a few months old.

Research in environmental psychology focuses on the impact of the physical environment on social behavior. As a result of such research it is apparent that factors such as crowding, noise, heat, and air pollution have important effects on social relations. Indeed, they seem to affect behaviors ranging from willingness to help others to crime and collective violence.

In 1980, anthropologists began plans to extract a deep-sediment core from the floor of a tropical African lake. The ultimate goal of the project is to unlock the environmental and climatic information contained in waterlogged sediments and, through the study of pollen and other biological and chemical data thus obtained, to reconstruct the shifts in climate and the environmental consequences over a period of several million years. These data will be unique because climatologists, biologists, and anthropologists can now accurately reconstruct only the past 50,000 years. Thus, the African deep-lake core should permit accurate assessment of the environmental background against which early human physical and cultural development took place.

Transduction in the Eye

All organisms recognize and respond to stimuli in their environment. Understanding transduction, the process by which sensory receptors transform physical energy such as light or sound into neural signals recognized by the brain, is one of the key areas of research in contemporary neuroscience. In the past year substantial progress has been made in describing the biochemical processes involved in the transduction of light within the eye during vision.

Theodore Williams of Florida State University has recently refined our understanding of the role of the visual pigment, rhodopsin, in visual excitation. Within the retina of the eye, two types of cells carry on transduction—the rods and the cones. The rod photoreceptor cells contain rhodopsin, a visual pigment containing a protein, opsin, and a tightly bound molecule of retinal, a derivative of Vitamin A. The opsin is closely associated with lipids—fatty substances that compose the rod membrane. Williams has observed that when light strikes a rod photoreceptor, the shape of the rhodopsin molecule is altered. Using techniques from physical chemistry, it has been demonstrated that a distortion occurs in the shape of both the Vitamin A-derived portion of rhodopsin and the protein, opsin. The change in the shape of opsin apparently allows an increase in lipid motion, making the rod membrane more permeable and allowing other molecules to pass through it.

Although these recent observations are significant, a complete understanding of visual transduction requires a thorough description of what further changes occur in the rods once the permeability of the rod membrane has increased. One possible mechanism of subsequent events in visual excitation suggests that the increased permeability of the rod membrane leads to an increased concentration of calcium ions within the nerve cell. It is believed that this increased calcium effectively blocks the normal entry of sodium ions into the cell, causing the interior of the rod to become more negatively charged (hyperpolarized). It is this change to a negatively charged state within the rod which the brain recognizes as the presence of light.

In another attempt to determine how hyperpolarization occurs, cyclic GMP (guanidine monophosphate) is currently being investigated by Richard N. Lolley of the University of California, Los Angeles. Studying human and cattle retinas, Lolley has found that levels of cyclic GMP are unusually high in the dark. As soon as the rod is exposed to light, levels of cyclic GMP fall dramatically. According to his hypothesis, light falling on the rod would activate a particular enzyme (phosphodiesterase) in the rod membrane which destroys cyclic GMP. Such a reduction in cyclic GMP initiates a cascade of biochemical events which modulate the permeability of the cell membrane to ions. One enzyme in particular, protein kinase, is deactivated in such a manner that the normal entry of sodium into the cell is blocked. The lessened concentration of sodium causes the interior of the rod to become more negatively charged, indicating to the brain the presence of light.

The biochemical study of transduction phenomena is providing a clearer understanding of two phases of transduction: how the binding of stimuli to a receptor leads to neural signals and how the internal chemistry of the nerve cell changes as a result of the stimulus binding. Research on transduction, particularly work with cyclic GMP and other nu-

cleotides, may also help clarify the role of such common chemicals as caffeine and aspirin on stimulus reception.

Animal Communication

Communication between individuals has long been a major focus of research on animal behavior. Like humans, most animals use several modes of communication, including odors, visual signals, and vocal signals. Recent research shows that, contrary to previous thought, many kinds of animals use signals that are rich in specific meaning and thus resemble "symbolic" communication.

The discovery that such apparently stereotyped vocalizations as bird song actually have geographic dialects has led scientists to look for other variations in animal signals. For example, Millicent S. Ficken of the University of Wisconsin at Milwaukee has found great variability in a complex call of the black-capped chickadee. Any individual chickadee produces all of the syllables found in a local population, but the specific ordering of syllables differs. A few orderings occur throughout the population, some are unique to a flock, and some are unique to individual birds. Whether or not chickadees recognize flock membership or even the individual identity of the signaler may be revealed by further research.

Variations in song repertoire in other species have been demonstrated to have specific functions. Peter Marler and an associate at Rockefeller University have observed that male red-winged blackbirds with large numbers of song types are generally older birds that acquire larger and better territories and attract more mates than males with smaller repertoires. When territorial males were experimentally removed, areas "defended" by loudspeakers that broadcast eight different song types were less frequently trespassed upon by other male redwings than were areas where only a single song type was played.

Sharing of song types has been studied in indigo buntings by Robert B. Payne of the University of Michigan. Payne found, as expected, that adult males had greater reproductive success than did first-year males. His striking discovery, however, was that those first-year males that mimicked an adult neighbor's song greatly increased their reproductive success. Male indigo buntings can distinguish among individuals by their songs but may mistake one bird for another if the two birds have the same song. Payne concludes that song sharing enhances the ability of a young bunting to defend a breeding territory by leading other males to mistakenly identify the young male as his older territorial neighbor. Thus, in addition to identifying the species of bird and the location of territories, bird song can also transmit information—and even misinformation—about the social status and the individual identity of the signaler.

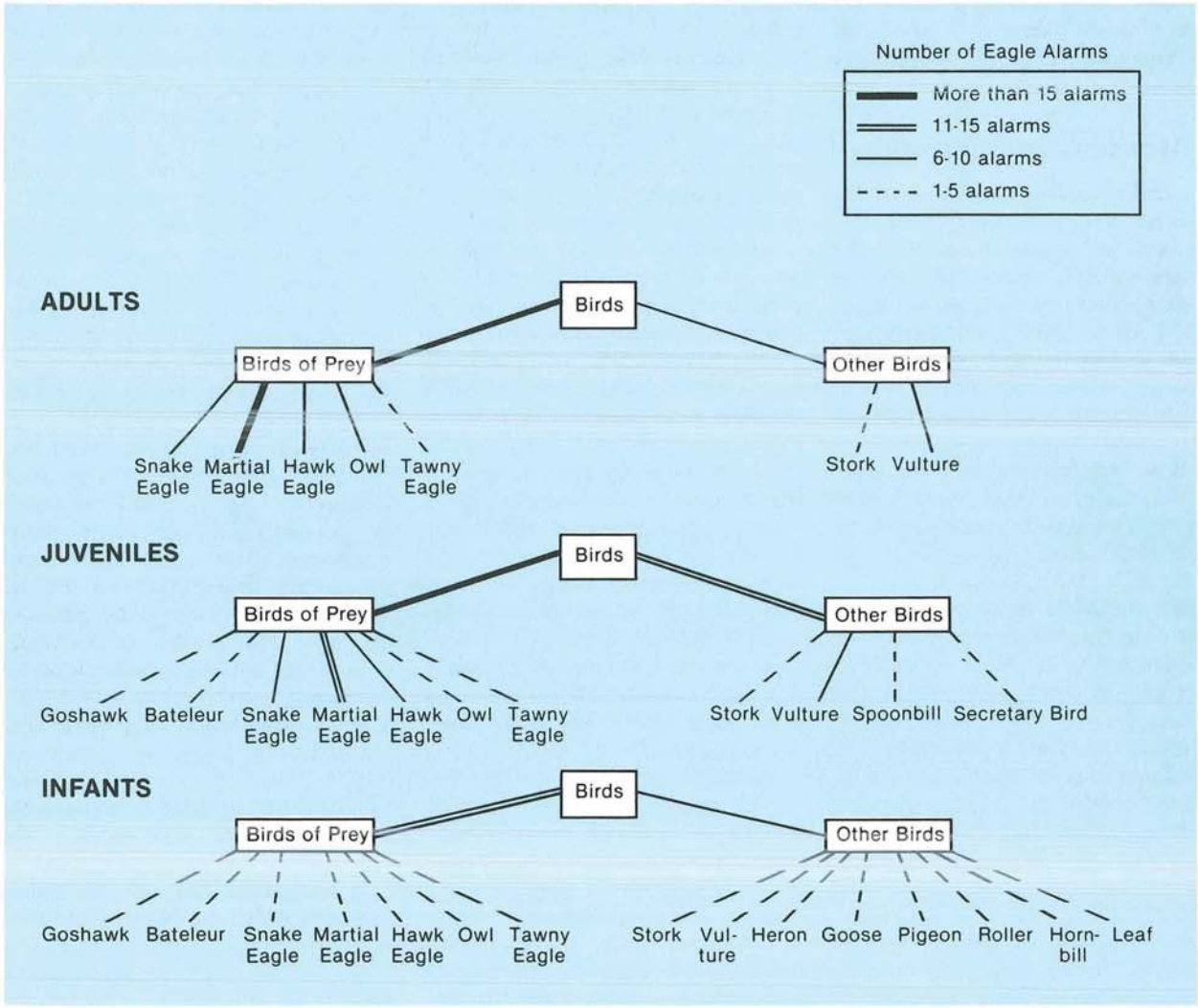
Among mammals, information that can be transmitted between individuals by vocal signals has also been found to be much more specific than previously believed. For example, Donald H. Owings of the University of California, Davis, has discovered that California ground squirrels give different alarm calls to identify different kinds of predators; birds of prey, snakes, badgers, and other carnivores each evoke distinctive alarm calls. Furthermore, the "carnivore" signal differs depending on the speed with which a predator is moving. Thus, the calls used by these ground squirrels are far more than merely ambiguous signals that some danger is near; they contain great amounts of information about events important to survival.

Vervet monkeys make effective use of the information that their distinctive alarm calls contain. Thomas T. Struhsaker of the New York Zoological Society discovered more than a decade ago a remarkable array of vervet alarm calls to which other vervets react in a specific way, depending on their current circumstances and the class of predator. For example, when a vervet sights a snake, it produces a distinctive call to which other vervets react by looking down at the ground around them. When a vervet gives the "leopard" alarm, its companions flee into the trees. However, when a vervet gives the "eagle" alarm, other vervets flee from treetops and open areas into thickets. These eagle alarms become much more specific and functional as a monkey develops from infant to adult. Recently, Robert M. Seyfarth, Dorothy L. Cheney, and Peter Marler played back tape-recorded vervet alarm calls when no predator was present and found that the monkeys reacted appropriately to the particular signal. Thus, it is now clear that animal communication is much more "symbolic," and more similar to human communication, than was once thought.

Development of Cognitive Competence

Newborn infants cannot walk. Later they learn to crawl, and then to walk in a gait unlike that of an adult. Finally, they can walk, skip, run, jump. No one is surprised at this sequence, since we all have observed it many times and judge an individual child's development against this developmental sequence. However, in the realm of cognitive capacities—using numbers, solving problems, reading, categorizing—we often judge a child's competence by comparing his/her performance to what adults do.

Now it is becoming clear that children *can* do many things earlier than they were previously thought to be able to. A vivid example comes from the work of Rochel Gelman at the University of Pennsylvania. An illustrative standard task given to young



Sounds of danger. This experiment with vervet monkeys shows how warning alarms become more specific as the animals mature. The presence of virtually any bird will elicit an "eagle alarm" from an infant, which perceives little difference between predators and non-predators. Juveniles and adults are increasingly discerning. Such communications are highly specific (there are "leopard" and "snake" alarms too) and alert other monkeys to take appropriate evasive action.

children involves a row of ten flowers and a row of ten vases, with each vase directly below a flower in one-to-one correspondence. Children, when asked whether there are the same number of vases as flowers, invariably answer yes. However, when the same number of flowers is spread out so that the length of the line is increased, children typically say that the two lines do *not* contain the same number of items. In conventional terminology, then, the young children are said not to be able to conserve number; they seem not to be able to realize that the number of objects in an array remains the same under simple transformations like spreading them out. Such research suggests that there are things we cannot teach children at early ages, because they lack the cognitive capacity for them.

In an attempt to find out what young children *can* do, not what they cannot, Gelman devised the "magic experiment." The magic experiment involves the presentation of two plates, one with three plastic toys and the other with two. The child

Children's learning. Experiments that use novel methods to assess the cognitive capacity of children—such as this simple test that asks them to compare numbers of toys in terms of winners (more) and losers (fewer)—are showing that young children may have greater learning capacities than commonly believed.

was told that the one with fewer toys was the "loser" and that the one with more toys was the "winner." When the numbers were transformed, children of ages at which they were expected to "fail" this test of conservation of number were indeed able to identify the "winner" and the "loser."

Even more impressive was the evidence that children as young as two years old can count, but not the way adults do. In general, they tended to use number words differently from adults, though consistently. Thus, a particular child might always count the objects in the following way: "One, six, nineteen, seven. . . ." However, that child would always use the word "nineteen" to refer to the third item in the set. Through the magic experiment and others like it, a picture of the capacity of young children to use numbers has begun to emerge.

Other investigators have begun to study what children can do in other realms. For example, David Klahr of Carnegie-Mellon University has begun to uncover problem-solving capacities in preschoolers that were hitherto unexpected, simply by modifying a standard puzzle, the "Tower of Hanoi," so that it is sensible to preschoolers. Deborah Kemler of Swarthmore College and Linda Smith of Indiana University are studying the way infants and children group objects on the basis of their observable characteristics, trying to understand the changes that take place as a child grows, not simply observing that at certain ages children act more or less like adults.

The work of these and many other investigators has a unifying theme: It tries to understand what children can do, not to catalog what they cannot. It paints a picture of young children quite different from that which has permeated our educational system. As the picture becomes more complete, it should enable educators to develop more effective curricula for children that build on their true cognitive capacities.

Contemporary Complex Social Systems

The study of contemporary social systems, characterized by such processes as urbanization, migration, adaptation, and industrialization, has recently become a major interest among social and cultural anthropologists. Their interest has been heightened by a turning away from the popular concepts of the "melting pot" and the homogenization of cultural subgroups and a realization of the plural character of both our own and other societies. Indeed, as Hispanic and Asian immigration to the United States continues, our Nation is becoming more diverse. For nations built largely of and by immigrants, such as the United States, Australia, and Argentina, an understanding of the process by and extent to which accommodation by hosts and guests takes place is a major concern. The rate and extent of any mutual accommodation has far-reaching social, political, and economic implications for the receiving society, the sending society, and the immigrants themselves.

William Douglass of the University of Nevada is undertaking the systematic documentation and analysis of the process of accommodation of immigrants to Australian society. In the 1950s Spanish Basques and Abruzzesi Italians were recruited to become labor migrants in the sugarcane industry of North Queensland, Australia. Thousands of individuals responded to the employment opportunity. Both groups entered Australia under similar circumstances, facing similar language handicaps and lack of formal skills.

By the mid-1960s the sugarcane industry became mechanized and the Basque and Abruzzesi cane cutters lost their jobs. Some chose to remain

in the sugarcane areas after finding alternate employment, usually in agriculture; some migrated to Australian towns, and yet others returned to Europe. Douglass is collecting data on all three groups: agricultural, urban, and returned migrants, and making comparisons with previously studied Basques and Abruzzesi in Spain and Italy. Using interviews, surveys, archival research, and participant-observation, he is determining the role of ethnic and national identity in adaptation to living in a different society, the effect of returned migrants on patterns of migration and social change in the migrant-sending communities, and factors influencing economic and social success in rural and urban areas of the society receiving the immigrants.

The kinds of adjustments migrants have been able to make to rural and urban Australian society have affected their occupational choices, income, social networks, family structure and marriage patterns, political participation, use of educational and health facilities, and the like. A number of the Basque and Abruzzesi would-be immigrants have returned to their places of origin, permitting investigation of the extent to which returnees' perceptions of their experiences (positive or negative) influence the behavior of others.

The work of Douglass and of other anthropologists working in the United States, Africa, Asia, and Latin America is developing a cross-cultural understanding of the processes and problems surrounding migration and accommodation by migrants and hosts. This understanding contributes directly to our comprehension of the nature of plural societies and to issues of national and international policy confronting the United States.

Social and Economic Science

This year marks 20 years since NSF established a separate division for the support of fundamental social science research. Research supported during these two decades has resulted in an improved understanding of how the economy works, how societies and individuals organize themselves politically, socially, and spatially, and how they change. This social change—what causes it, how it happens, and what its effects are—represents a major focus of interest for the social sciences. Although the perspective of a particular event will depend on the time span involved, the unit of analysis, and the behavior under study, the collection of many studies converges on understanding the nature and implications of social change and human adaptations to it. The goal of such research is to provide valid and verifiable findings on processes and consequences so that social phenomena can be understood and anticipated.

The past two decades were replete with changes, and one of the tasks of the social sciences is to identify those having long-term consequences for society. Accordingly, there is an effort to develop better measures of social and economic conditions, which is reflected in the Government's statistical information collections, including the census. To help extend this valuable data base, NSF is supporting an effort at the University of Wisconsin to organize the 1940 and 1950 census materials in a manner that will make the data compatible with later censuses. The work should be completed at approximately the same time as the 1980 census is available for study. It will then be possible to conduct research on topics such as migration, education, employment, and family composition over a long and significant period. Changes can then be traced in detail and reliable conclusions reached on differential rates of change.

The 1980 census has also brought to public attention concern about measurement methods. This has been an area of special emphasis in the NSF programs. For example, NSF supported a review by the Committee on National Statistics of the National Academy of Sciences of concepts and methods for treating nonresponse and missing data in surveys. It focused on the need to improve the methods for treating incomplete data, to determine how the nature of missing data has been changing, and to understand the implications of these changes for the analysis and reporting of survey findings. The report, which will be available in 1981, will offer ways of increasing the reliability of survey results through the application of stronger statistical adjustments and better practices in sample surveys.

It is evident that social and economic concerns will draw substantial national attention in the decade ahead. Even where the precipitating factor may be a new technology or the exhaustion of a nonrenewable resource, it is the social and economic consequences that become major national problems. The tools, techniques, and insights that the social sciences have acquired during the past two decades may be expected to provide a basis for improving our current situation and for advancing in the future.

Election Studies and Surveys

The subject of elections and public opinion polls has been prominent in 1980—both a presidential election

year and a decennial census year. NSF has provided support for the National Election Studies, based at the University of Michigan, which address such topics as voter participation, the influence of the media, and the role of party identification in electoral choice. In the past year two important reference volumes appeared: *American National Election Studies Data Sourcebook, 1952–1978* and *American Social Attitudes Data Sourcebook, 1947–1978*. These books provide valuable data on long-term trends in political and social attitudes and behavior. They have already been used extensively by journalists, political analysts, and social scientists to appreciate the current situation of the American population within the larger context of societal change.

The use of the sample survey as a means of collecting information on opinions, attitudes, behavior, and values is well established, although there has been concern over the limitation of the technique. NSF has been leading the efforts to improve the operation, cost-effectiveness, and, above all, the reliability and validity of such surveys. In addition to concerns with statistical problems, NSF is supporting experiments in the techniques of survey methods.

George Bishop and his colleagues at the University of Cincinnati conducted one such experiment in which they assessed the incidence and consequences of "pseudo-opinions"—the problem of people claiming opinions when they really have none. They asked respondents about a nonexistent "Public Affairs Act of 1975" and found that fully one-third of the sample volunteered opinions. These people have a number of distinguishing characteristics. For example, they are politically more liberal than others on domestic policy questions. Most distinctly, however, these pseudo-opinions reflect basic social-psychological dispositions such as "saving-face" (i.e., self-esteem) and one's sense of trust in other people and institutions. The distorting effects of pseudo-opinions can be quite serious in surveys that do not compensate by using questions designed to separate those without real opinions.

Survey Measures of Subjective Phenomena

In contrast to surveys that measure behavior or levels of information, national surveys now produce a growing complement of statistics designed to measure subjective phenomena. Subjective measures are a vital addition to traditional national statistics in that they provide insight into how people perceive objective conditions. Such data are an essential source of information on people's values and aspirations.

The increasing use of measures of subjective phenomena has been accompanied by growing academic research activities, such as psychological studies of national well-being, investigations of trends in sex-role stereotyping, changes in the public's expressed tolerance of nonconformity, the relationship of economic development to individual satisfactions, confidence in Government, and intentions regarding childbearing. Increasingly, this work, which is partially Government-supported, is finding its way into public and private decisionmaking.

As the number of survey-based measures of subjective phenomena has grown, there has been a corresponding increase in concern over the meaning of what the measures predict or explain, their reliability and stability over time, the extent to which those influenced or affected by the derived findings appreciate the limitations as well as the significance of such results, and the adequacy of current practices regarding presentation and interpretation.

Efforts to assess the extent and seriousness of the problems affecting survey-based measures of subjective phenomena and to make recommendations for dealing with them are under way under the auspices of the National Academy of Sciences. Two reports will be produced: One, written for the public and those public administrators who use subjective surveys in their work, will discuss the appropriate uses of subjective measures, the uses that are unwarranted or potentially misleading, the sources of error that affect the underlying data, and the implications of these errors. A second, more technical report will synthesize available research and provide technical guidance concerning the implications of observed anomalies in the measurement of subjective phenomena. This report will also suggest strategies for improving the collection, processing, and presentation of such data, consider the potential for the manipulation of survey estimates, and make recommendations concerning the analyses of error structure that should accompany presentations of such data. High on the panel's agenda is the subject of nonsampling errors, which include the simple and interactive effects of question wording, survey context, and other survey and organizational variables. The panel will also look at the statistical modeling of the total error structure of subjective survey estimates as well as the research designs required to estimate total error models.

Theory of Collective Action

Under what conditions will individual citizens contribute money to groups that seek public goods such as clean air or water? The question is a major one in a society where individuals are largely motivated by incentives and rewards having value or utility to themselves. Why should not most people wait for others to invest in campaigns for public goods and then "ride free," and why should

people expect their small contributions to have any impact on a major public goods campaign? Resolution of these questions is important to understanding collective action in American society. Recently completed research on the current environmentalist movements by Robert C. Mitchell, a sociologist at Pennsylvania State University, has provided new evidence bearing on these issues.

Under certain conditions, Mitchell found, collective action may occur despite the theoretical barriers of the free-rider problem and the perceived inconsequentiality of small contributions. He developed a framework for testing the leading theory of collective action, which was developed by Mancur Olson, Jr., a University of Maryland economist. Mitchell used information from a mail survey of 3,000 members of five national environmental groups. He was testing the assumption that if such people perceive a high utility for a public good such as cleaner air or water or a disutility for polluted air or water, and also perceive an efficient way to contribute to groups that seek to maximize these goods, sufficient numbers of them will contribute to viable lobbies even when their individual private goods incentives are minimal. The empirical analysis confirmed the hypothesis that a key factor motivating contributions to environmental groups is a fear that things will get worse. Thus the "no exit" quality of environmental ills, which means that people cannot escape them, helps to overcome the inevitable tendency to rely on others to achieve things that will happen whether or not the individual makes any contribution.

Determinants of Population Growth

The study of population involves sociologists, geographers, political scientists, and economists, as well as demographers. Basic research in population addresses issues pertaining to global as well as national and local problems involving economic development and the determinants of fertility and mortality patterns. Of particular importance today are the causes of migration, its effects on urbanization and rural depopulation, as well as the costs and benefits of migration resulting from unemployment or occupational advancement. Population research also focuses on the methods and techniques of measuring these relationships, as well as the quality and availability of data required to understand the interactions between individual behaviors, societal policies, and historical events.

The demographic transitions of developing societies—from high to low fertility and from high to low mortality—can generally be explained as consequences of modernization, urbanization, and advances in education levels. These mechanisms were well illustrated in a major conference on European fertility organized by Ansley Coale of Princeton University as part of the European Fertility Project.

Among the principal findings were that declines in fertility occurred in virtually all the provinces of Europe, from diverse initial conditions, and were the result of increasingly effective deliberate control of fertility by married couples. These declines were long term and irreversible, often occurring in spite of governmental or religious opposition. The most promising explanations for the universality of the decline build on the themes of: (1) shifts in economic advantages of parenthood and the direction of intergenerational flows of income, and (2) an increasing secularization of attitudes about voluntary control. The implications of these results for currently developing countries are that fertility reduction can occur in populations that are heavily rural, illiterate, and agriculturally employed and that pronatal customs and beliefs can delay, but not prevent, the decline. NSF supported this project in its formative years; the papers, discussion, and forthcoming book represent the culmination of a large body of research.

Science Education

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NSF, through its Science Education programs, has broad responsibility to strengthen science education at all levels across all fields of science. Historically, education in the sciences has been regarded as the supply mechanism for the human resources required by the scientific and technological enterprise. Science Education at NSF has generally emphasized the needs of the academic sector of that enterprise, but in recent years has also turned its attention to some broader needs of the economy, such as the adequacy of the training that engineers and other professionals receive for industrial employment.

Additionally, many professions and occupations that once had little scientific or technical content now require a reasonable level of competence in these areas. Unfortunately, there is widespread concern that the technical skill level of the work force is simply not adequate. Moreover, the ability of science and technology to contribute to the economy and the national welfare depends not only on the inventiveness and technical competence of its practitioners but also on the degree to which its results are understood by others and can be assimilated into our social structure and institutions.

Reflecting this situation, NSF's two major goals in Science Education are: (1) to help all citizens increase their basic understanding of science and its contributions to the quality of life; and (2) to assure a stable flow of the most talented students into careers in the sciences, with particular reference to increasing the participation of minorities and women.

These two goals are implemented by programs whose objectives are to:

- Provide high quality training in science for specially selected students in programs ranging from the secondary school through postdoctoral levels.
- Revitalize subject matter knowledge of both precollege teachers of science and undergraduate science faculty.
- Improve undergraduate science instruction at two-year and four-year colleges and universities.
- Support both research on how science and mathematics are learned and development of more effective instructional techniques and materials for use at all levels of education.
- Improve the public's understanding of science and its effect on daily lives and increase people's ability to participate knowledgeably in the resolution of science-related public policy issues.

During the past year two long-term NSF programs were transferred to the new department of Education—the minority institutions science improvement program and the early elementary (K-4) portion of the

Table 5*
Scientific Personnel Improvement
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Faculty Improvement	413	$10.14	387	$10.03	406	$11.79
Minorities, Women and Physically Handicapped	68	2.31	81	2.36	64	2.23
Student-Oriented Programs	343	5.10	319	5.42	295	5.11
Fellowships and Traineeships	1,653	14.16	1,744	15.26	1,560	13.96
Total	**2,477**	**31.71**	**2,531**	**33.07**	**2,325**	**33.09**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

way to augment communication of the findings to different audiences, NSF selected nine organizations to analyze the studies independently. The reports, published in *What Are the Needs in Science, Mathematics and Social Science Education? Views from the Field,* provide perspectives as seen by those organizations.

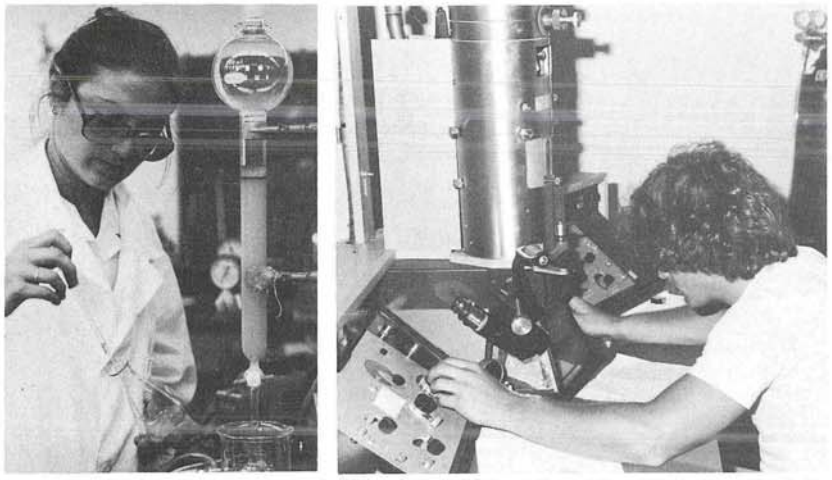
Additionally, NSF published the *Science Education Databook,* a compendium of quantitative information portraying U.S. science education, which should be valuable to those concerned about the condition of science education in the United States.

precollege teacher development program—although NSF provided administrative support for both for the balance of the year. NSF is currently establishing appropriate consultation and advisory mechanisms with the new department and planning for future collaboration.

The year was also marked by the appearance of two important publications. NSF's recently completed study of the status of precollege science education appeared in seven volumes totaling nearly 2,000 pages. To help make use of the results for NSF's own policymaking, and as a

Scientific Personnel Improvement

A major goal of NSF programs in scientific personnel improvement is to promote the training of a cadre of young scientists to assure a continuing input of highly qualified personnel to the Nation's scientific future. This requires programs that address a broad spectrum of the public at many levels through a variety of approaches. This spectrum also includes programs that clarify the nature of the scientific enterprise to qualified persons who have not pursued traditional careers in science or to those who are simply trying to cope with our increasingly technological society. The following items illustrate the philosophy guiding this mixture of program mechanisms and the programs' impact.



Undergraduate research participation. At the University of Maryland a student (left) attempts the synthesis of the organic compound loganin; using an electron microscope, an Oklahoma State University student (right) inspects the effects of nematodes on wheat roots.

Science for All Students

At both the precollege and college levels, programs are designed to improve the teaching of science to all students. This approach aids in identifying and encouraging students who may discover an otherwise dormant interest in a science or science-related career. At the same time, students who will not pursue scientific careers benefit from improved classroom teaching, resulting in better current and future public understanding of science.

In 1980 NSF programs provided intensive summer courses and academic year workshops in science to 15,500 classroom teachers in grades 5 to 12. Comparable efforts are geared to updating the science base of undergraduate college teachers, with about 3,000 two-year and four-year college faculty attending Chautauqua-type short courses, 300 supported as participants in college faculty conferences, and 70 college science teachers pursuing up to a full year of individually tailored programs of study or research with the aim of bringing science to the classroom from new perspectives. It is important to note that all these programs have a substantial multiplier effect. For example, each college faculty participant will encounter 100 to 200 different undergraduate students annually. Nationwide, about 19,000 teaching faculty at precollege through college level participated; more than two million students are expected to benefit indirectly.

Student Contact with Scientists

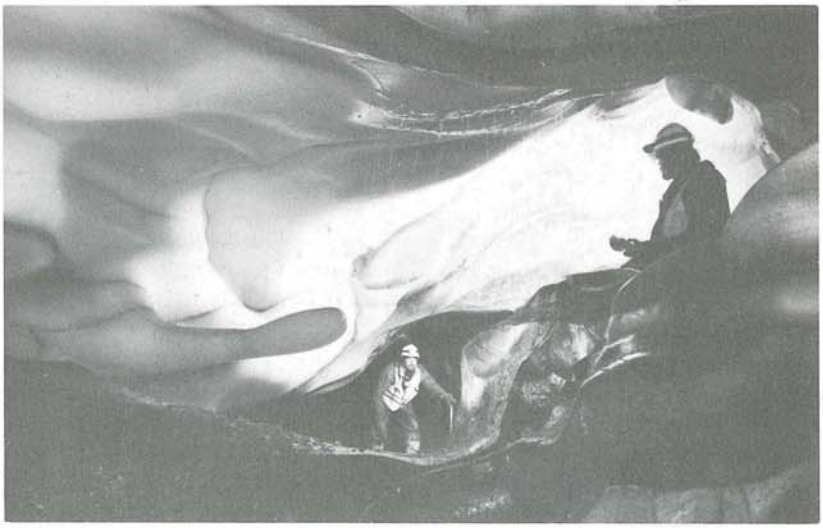
Students interested in science, but who have not yet made a formal career commitment, are addressed by NSF's student-oriented programs, which give them some early laboratory exposure to scientific research. For the students the reality is often much different from expectation, and such exposure facilitates a better in-

formed career decision. For others, the experience simply inspires them to greater diligence in pursuit of a science career. Both of these results lead to a more realistic understanding of science and to the improvement of the Nation's pool of talented scientists.

In the student science training program, approximately 4,400 high-ability high school students spent up to ten weeks of the summer of 1980 participating in research in active scientific laboratories under the direction of mature investigators. A specially focused effort in this area provided nearly 230 research apprenticeships for minority high school students. At the college level, 1,110 students were given similar opportunities at a more advanced level of participation through the undergraduate research participation program. Additionally, over 450 upper level college students and beginning graduate science students were supported through the student-originated studies program to carry out summer research projects of their own design, with limited guidance by faculty members.

Postbaccalaureate Science Career Opportunities

Science students reaching the postbaccalaureate level of training are a self-identified group which is much smaller than the prebaccalaureate population. With the smaller numbers, direct support of training



Student science training. High school students participate in glaciological research in Alaska's Juneau Icefields during the summer of 1980. Nationwide, nearly 4,500 high-school students had summer research experiences.

for the most able among this group becomes feasible. A limited number of students (460) at or near the beginning of their graduate training in science were successful in a national competition for NSF graduate fellowships. These fellowships provide both cost-of-education allowances and stipends for three full years of training. These new fellows joined more than 900 fellows continuing on their awards from previous years. At the postdoctoral level, 50 very high-ability recent science Ph.D.'s were identified in a national competition and awarded fellowships to support them for one year of additional training.

Opportunities for Minorities and Women in Science

The minority graduate fellowships program, which parallels the traditional graduate fellowships program in design and operation, offered 50 new three-year fellowships in 1980. These new fellows joined approximately 100 continuing fellows from previous years. In addition, NSF awarded 48 three-year graduate traineeships for study at 14 minority institutions.

Of the 152 minority institution graduate trainees on tenure in 1980, 82, or 54 percent, were women. Of the 1,380 graduate and minority graduate fellows on tenure, 453, or 33 percent, were women. These figures compare well with the 1977 survey statistics of 30 percent national full-time enrollment of women in graduate science and engineering.

NSF also conducts two programs to assist women who might like to consider, or reconsider, careers in science. The first supports local science career workshops to present the various career options available to women. These sessions have been offered for undergraduate students, graduate students, and postbaccalaureate women who are not presently in graduate school, but who are unemployed or underemployed in science. Seventeen such projects were established in 1980 to reach 3,000 women. The second program of science career facilitation projects is designed for women with degrees in science but who need some specially structured education to enter or reenter scientific employment. Six new awards in this area were made in 1980 for 270 women.

There are potentially about one million eligible participants for NSF's four faculty improvement programs. Obviously, the percentage of eligible participants reached must remain very small; this year it was about 1.6 percent. However, because each teacher-participant is involved in each subsequent year with many students, as was pointed out earlier, there is a large leverage for the improvement of student understanding of science. In addition, teacher participants often contribute to their colleagues' science understanding when they return to the classroom; this effect is again multiplied through transfer of knowledge and attitudes to many students.

In the precollege teacher-development-in-science program, 81 of the 312 projects (26 percent) deal with societal-issue topics. Of the Chautauqua-type short courses, 22, or 41 percent, are focused on such topics. One of the nine college faculty conferences deals with these issues, and in the science faculty professional development program, 14 of the 70 participants (20 percent) are involved in research related to societal issues. Among the topics considered are pollution, the environment, math anxiety, aging, earthquake education, marine science, bioethics, multiculturalism, energy, and labor in American society. These projects illustrate the role that several disciplines can play in an interdisciplinary approach to an understanding of complex issues that are of concern to society generally.

Attracting and Supporting Minorities in Science

NSF continually monitors its level of effort in supporting minorities underrepresented in science through all of its science personnel improvement programs. Overall, in 1980, $5.7 million, or 18 percent, of the program funds were used in direct or indirect support of minorities. Of that amount, $2.7 million was in support of specifically targeted programs, while $3.0 million involved minority scientists or potential scientists in the absence of any special minority targeting.

The research apprenticeships for minority high school students have the youngest minority target pool. Interest in the program this year was so intense that only one out of ten applicants could be supported. Program operations are basically identical with the student science training program, except that the apprenticeships include stipend support. Indeed, 97 percent of the apprenticeships project directors have had student science training experience at some point. This dual experience should benefit the operations of both programs in the future. The research apprenticeship program also allows project directors to experiment with recruiting techniques and to test the effectiveness of retention mechanisms. One of the projects, at the Illinois Institute of Technology, will be making links to industry throughout the coming year.

Minority institution graduate traineeships are awarded to predominantly minority universities offering at least the master's degree in one or more of the sciences and engineering. The program is now in a steady state, with about 150 trainees currently on tenure. Grantee institutions use the funds to cover the cost of education and stipends for trainees they select from among their graduate students. Such awards are used as recruitment devices by those

universities with proven records in minority graduate science training.

For some trainees, the M.S. degree is viewed as terminal, and they go directly into industry or academia. For others, traineeships provide the opportunities to round out their education prior to entering Ph.D. programs at other institutions. At one minority institution (Texas Southern University), approximately 80 percent of the trainees who have earned the M.S. degree have gone on to doctoral programs. Thus, this effort, begun in 1974, has proved to be an effective springboard for encouraging minority students to seek advanced science degrees.

The minority graduate fellowships program, which began in 1978, provides a second mechanism for encouraging minority students to seek advanced training in the sciences. It, too, is in a steady state of about 150 fellows currently on tenure. Unlike the traineeships, this program does not tie support to particular institutions. Rather, individual minority students at or near the beginning of their graduate study apply directly to NSF in a national competition. Winners of fellowships take their 3-year awards to universities of their choice—currently 61 institutions throughout the country. Although the program is highly competitive and can support only about one out of eight applicants, 30 percent receive Honorable Mentions in the competition. Many leading graduate schools use the Honorable Mention designation as a basis for intensive recruitment and for allocating local support for graduate students. Thus, like the long-standing graduate fellowship program, this relatively new program is showing both a broad direct impact and a multiplier effect that extends beyond those who can be supported directly.

Science Education Resources Improvement

Science education resources improvement (SERI) programs are geared primarily to science instruction for undergraduate students. These students attend institutions that are remarkably diverse in size, mission, source of support, and history, and range from the small liberal arts college to the undergraduate components of major research universities. They include community colleges, private and public colleges, as well as institutions in isolated settings and urban "commuter" sites. Whatever their history, the makeup of their student body, or their special role in higher education, each shares with the others an array of problems in providing quality instruction in science and engineering.

To be responsive to this diverse clientele, NSF maintains a variety of competitive programs to help colleges and universities keep their instruction in science up to date. Some need very specific instruments or equipment, others need faculty time for refurbishing courses or creating new ones, and still others need support for coordinated actions to make their teaching of science vital and timely. This updating of subject matter, minor renovation of facilities, staff development, and acquisition of instruments and equipment for instruction in science continues to be the regular business of SERI programs.

In recent years two very marked trends have surfaced. First, the microprocessor and the computer, which have created a near revolution in collecting and processing information in science and engineering, have naturally had a major impact on the instructional process. The silicon chip and other high technology items are rapidly becoming everyday tools for extending the capabilities of teachers and also relieving them of many dull, repetitive tasks. Second, faculty members are developing a keener interest in moving new research results quickly into their teaching and in learning new approaches and techniques in science teaching. To avoid the waste of reinvention of curricula, higher education is creating networks for learning what others are doing.

This same kind of communication of information is being supported at the precollege level, and a number of informal networks have been created to serve those needs. These networks extend NSF's efforts to provide decisionmakers at the precollege level with a wide range of information on what is currently available in instructional methods, materials, and technologies.

Overall, NSF supported more than 400 SERI projects in 1980. The instructional scientific equipment program made 218 grants averaging $14,000 each to 181 institutions in 41 states plus Puerto Rico, Guam, and the Virgin Islands. Its companion program, local course improvement, made 125 awards ranging from $4,000 to $25,000 in support of development and evaluation of instructional materials, laboratory experiments, and other improved instructional strategies at the local level. These awards went to two- and four-year colleges and universities in 41 states. The comprehensive assistance to undergraduate science education program supported 66 projects that embody a complex of institutional improvements in science instruction. These awards, which averaged $200,000, went to all types of undergraduate institutions in 32 states and Puerto Rico. A single large award for a Resource Center for Science and Engineering in Puerto Rico supports a

complex of activities from the precollege level to faculty research. Finally, this year's 35 information dissemination grants, ranging from $12,000 to $30,000, will support conferences and workshops to give school policymakers information to help them select science instruction materials and programs for their schools.

Puerto Rico Resource Center for Science and Engineering

In the past 20 years Puerto Rico has changed from a mainly agrarian society to one experiencing rapidly growing industries. Moreover, the dominant labor-intensive manufacturing sectors have been giving way to highly technical capital-intensive industry—mainly pharmaceutical, petrochemical, and electronics—that requires large numbers of highly skilled technical personnel. At the same time, however, many unskilled workers have been left without jobs, and many families remain below the poverty level.

The demand for highly skilled technical personnel, coupled with increased Federal and Commonwealth interest in strengthening postsecondary education systems, has brought a doubling of college and university enrollments in Puerto Rico in less than ten years. This sudden growth, a result of the commitment of these institutions to serve low-income students, has produced serious pressures on Puerto Rico's colleges and universities to develop and strengthen programs, faculty, and facilities. This pressure has been most notable in the sciences, where, with few exceptions, the institutions lack the resources to secure and develop the faculty and facilities needed to sustain quality science instruction and research. Furthermore, they have also lacked the resources to reach out to the community and promote the sciences and other technical careers among the many precollege students that have the potential to become scientists or engineers.

In 1980 the University of Puerto Rico, leading a consortium of nine institutions of higher learning, was awarded a grant to develop a Resource Center for Science and Engineering, the third in a series of major NSF awards initiated in 1978 to promote increased participation in science and engineering by minorities and persons from low-income families.

The University of Puerto Rico has adopted a three-part strategy for achieving its objectives. The first focuses on developing new doctoral programs in biology and chemical physics by strengthening programs in chemistry, marine science, applied mathematics, physics, and engineering.

Second, the Resource Center is developing activities that it is hoped will eventually reach all postsecondary students and faculty in Puerto Rico. Talented students are being selected to take advanced undergraduate courses and to develop original research projects; undergraduate faculty members are conducting collaborative research with Resource Center scientists and are undertaking individual research projects; and faculty members are receiving in-service training in seminars and workshops.

Finally the Resource Center is initiating a major effort to attract more precollege minority students, particularly low-income students and women, for science and engineering programs. Activities include short courses for high school students and programs to improve the knowledge of high school counselors about science and engineering careers.

The NSF grant of approximately $2.7 million will be augmented by more than $2.4 million of University of Puerto Rico and other external funds during the four-year duration of this project.

Table 6*
Science Education Resources Improvement
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
CAUSE	73	$13.47	72	$13.52	66	$13.28
Undergraduate Instructional Improvement	487	6.26	435	6.40	343	5.68
Minority Institutions Science Improvement	27	4.69	39	4.91	**	0.08
Resource Centers for Science and Engineering	1	2.79	1	2.74	1	2.75
Information Dissemination	34	0.72	36	1.03	41	1.27
Total	**622**	**27.93**	**583**	**28.60**	**451**	**23.06**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

** Note: The Minority Institutions Science Improvement program was transferred to the Department of Education during 1980. The indicated awards were made by NSF with Department of Education funds under an interagency agreement.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Individualized Instructional Strategies

Large lecture sections, each of hundreds of students, are common on college campuses. Though often supplemented by graduate-student-led recitation sessions and laboratory periods, these lecture sections form

the primary source of instruction for many students in introductory science courses. Large enrollments, limited numbers of faculty, and demands for cost effectiveness lead to the use of such lectures in many institutions. Yet slow learning, poor note-taking skills, or missed lectures can cause disastrous results for some students—many of whom are in their first semester of college and find themselves overwhelmed by the experience.

As a way to accommodate individual student differences in learning style, speed, and anxiety, Warren D. Dolphin of Iowa State University, with the assistance of a comprehensive assistance to science education grant, has recently implemented an effective set of instructional strategies. For three beginning courses in the biological sciences with combined enrollment of 5,500 students, study guides for students were written, and almost 10,000 test questions were stored in computer memory to form a large resource pool for test preparation under a wide variety of conditions. Also, a video playback center was established in the university library, and 128 videocassette lectures were produced.

Four instructional strategies in each course were then introduced and evaluated. The first strategy employed the standard classroom lectures, study guides, texts, and traditional testing. In the second, a self-paced testing plan was inserted into the instructional design. The third and fourth strategies added the videotaped lectures as optional supplements to the traditional and self-paced strategies (over 60,000 uses of the videocassettes were made over two years). All the strategies, or variations, were studied for their effect on student learning.

Four doctoral candidates from the Iowa State University College of Education evaluated the project, an activity that resulted in several theses and published papers. This type of activity is being increasingly encouraged by NSF as part of its effort to strengthen research in science education. Complex science education projects generate a wealth of information that, properly analyzed, can significantly improve the effectiveness of Federal funding.

The results of this study were most encouraging. They indicate that students with individual differences in ability, background, and personality could all gain academically when permitted to study under an individualized instructional strategy. Self-paced testing benefited students with poor high school science backgrounds or high test anxiety. Additionally, videocassette lecture viewing, as an adjunct to traditional study habits, appeared to benefit all students, not simply a particular subgroup. Overall, this project at Iowa State University has increased awareness of instructional innovation, improved instruction, and demonstrated that it is possible to adjust for individual differences within the context of large lecture sections.

Building Microcircuits

Digital wristwatches, electronic calculators, high fidelity equipment, and personal computers are examples of common products that reflect careful electronic and physical design to arrange necessary components within a very small space. In many cases a "thick-film hybrid microcircuit" provides the necessary transistors, diodes, and other electronic items.

Although its name is formidable, the thick-film hybrid microcircuit is simple in concept. The desired circuit is first drawn on a sheet of paper, much as a draftsman lays out the plans for a building. It is then photographically reduced by a factor of perhaps 20 and used as a pattern for printing the circuit on a small wafer of material. When the wafer is heated the printed lines become conductors, resistors, or capacitors, depending upon the type of "ink" used. Additional devices such as transistors, diodes, and larger resistors and capacitors are attached to complete the electronic circuit.

Electrical engineering students at the University of South Florida are taught the techniques of fabrication of thick-film hybrid microcircuits in three senior-level courses. Until recently a student could only produce two microcircuits per academic quarter because the image reduction part of the process was dependent on the schedule of the university photographic laboratory. A grant from NSF's instructional scientific equipment program (ISEP) for the purchase of photoreduction equipment freed the students from this dependence. A student now easily produces six or more microcircuits each quarter. The grant has also enabled the laboratory to acquire specialized soldering equipment so that a wider variety of electronic devices can be attached to each thick-film hybrid microcircuit. The quality of this laboratory experience is reflected by the experiences of former students, who report that they are well prepared to use the similar equipment in the electronics industry.

This well equipped laboratory is used not only for full-time undergraduate students, but also for the continuing education of practicing engineers. Twice each year the university offers a five-day intensive short course on hybrid microelectronics. Engineers from all parts of the United States attend this course, and each attendee is able to completely fabricate two hybrid circuits in less than four days. Overall, this laboratory is providing state-of-the-art instruction for 90 students and 30 practicing engineers per year.

According to Michael Kovac, present director of the laboratory, "The ISEP project was one of the seeds for

USF's proposed Center for Electronic Development and Research. This will be a joint undertaking of the university and local industry to build a laboratory facility for research in the areas of hybrid devices, novel thin-film sensors, and the computer-aided design of these and similar electronic devices. The facility will also be used for instructional purposes, and there will be some opportunities for student employment."

Science Education Development and Research

Science education continually changes in response to the evolving nature of science and society and their vital interactions. Development and research contribute to those changes by introducing new knowledge into the educational process, preparing people for new science-related tasks and problems, translating scientific knowledge into a form that can be understood and learned, capitalizing on new insights into the ways we learn, and helping people to cope with and participate broadly in our technologically based society.

Development and research are not separate processes; they interact in complex ways. Development not only provides new curriculum materials and ways to teach science, but also generates new contexts for science education research. Research in science education gives us new ways of viewing the processes of learning—the ways we develop scientific skills and knowledge. These programs at NSF are guided by three overall objectives.

- To increase the scientific literacy of all citizens, specifically their knowledge of scientific concepts, of methods and limitations of science, and of relationships among science, technology, and society. This is approached by projects both within the school system and in informal, out-of-school settings. These projects are frequently tied to the needs of all citizens to deal with events in our science-based society; examples include such topics as radiation from nuclear energy processes, selection of energy alternatives, or overuse of antibiotic medicine.
- To increase the access to scientific knowledge and careers of minorities, women, and the physically handicapped. Equality of educational opportunity can only have meaning if barriers to both knowledge and careers are eliminated or at least minimized.
- To increase the flow of new scientific knowledge into courses and other instructional materials. Much depends on the diversity of course materials available and whether what is taught represents the latest and most significant knowledge. Such knowledge is important to current concerns in productivity and the extent to which individuals can compete in the scientific and technical job market.

NSF responds to these objectives through its component programs, development in science education and research in science education. Development projects enable teams of scientists and educators to produce new science courses, new curricula, and new approaches to science teaching. Research projects include basic and applied research and synthesis of existing research to create and organize fundamental knowledge of science education. Beginning in 1979 and continuing in 1980, these projects have been concentrated in a number of areas of special interest and concern to NSF. These are:

- Science for the early adolescent.
- Improving access to careers in science for women, minorities, and the physically handicapped.
- Science literacy, and science, technology, and society.
- Technology applied to science education.

In addition, development projects have emphasized new knowledge and new skills—education for productivity—and research projects have

Table 7*
Science Education Development and Research
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Development in Science Education	92	$6.01	53	$8.18	52	$8.11
Research in Science Education.....	32	2.85	40	3.83	46	5.68
Total	**124**	**8.86**	**93**	**12.01**	**98**	**13.79**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

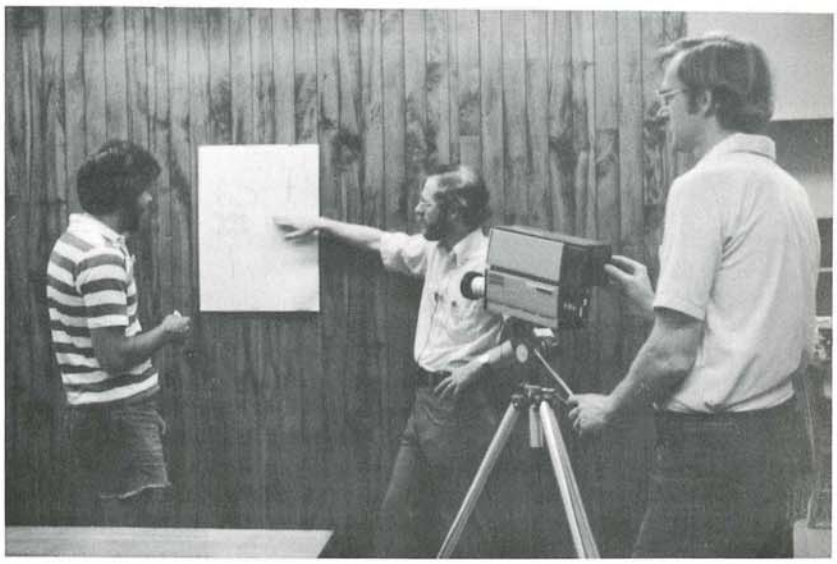
emphasized cognitive processes and the structure of knowledge. Pervading these special themes, where appropriate, are NSF responsibilities for testing ways to enhance dissemination of results and products and continuing education for industrial scientists and engineers.

Cognitive Processes and the Structure of Knowledge

Research into mental processes and the structure of knowledge in science and mathematics has received increasing emphasis by NSF for each of the past three years. Project support has grown from about $0.5 million in 1978 to more than $1.5 million in 1980. This reflects several factors, including the fact that NSF was virtually the sole source of support for research of this kind in 1980 owing to reductions in funds available from the National Institute of Education, with whom NSF had shared the responsibility for project support in prior years. The increase in NSF support in 1980 reflects other realities too, however, including the increase in interest in this type of research by scientists and mathematicians and the improvement in the quality of proposals being received.

But this growth is primarily a reflection of the greater degree of understanding and collaboration across disciplinary boundaries. Physical, mathematical, biological, behavioral, and computer scientists are increasingly familiar with one another's work. Some are prepared to collaborate, even to the point of willingly employing psychologists within physics departments and vice versa (which occurred at the University of California, Berkeley, and at Carnegie-Mellon University, for example).

The purpose of such research is to discover the mental processes and structures that underlie competence, skill, or "understanding" in some important area of science or mathematics. The general approach is to study intensively the knowledge and behavior of individuals at different levels of expertise, then identify consistent differences in knowledge and skills that might account for differences in competence.



How learning occurs. A student is observed as he thinks aloud while solving an algebraic problem. Analysis of many people solving the problem enables University of Massachusetts researchers to identify consistent misconceptions and patterns of reasoning.

This is usually preceded by a detailed logical analysis of the knowledge and skills that seem to be required. It is increasingly common for researchers to write computer programs that simulate understanding of the science or mathematics—using only the specific knowledge and processes inferred from the study of individuals. Because computers are extremely simple-minded and unforgiving, this forces one to make explicit "every little bit" of knowledge required in the process.

Research of this kind differs in important ways from most of the educational research that was undertaken in the past, particularly that which compared the effectiveness of different instructional programs on student achievement or attitudes. The ultimate objective—to increase the effectiveness of learning—is unchanged, but the more immediate goal is to explain, in considerable detail, what constitutes learning or knowledge. This necessarily requires a different method of research, namely intensive observation (and subsequent simulation) of individuals, rather than the aggregation of statistical data.

Several interesting findings emerge from recent research of this sort, particularly in projects studying competence in solving problems in physics or mathematics. One finding is that experts, when confronted with a problem to solve, consider it qualitatively before they begin a quantitative solution. That is, the expert engages in much more planning than the novice and is aided by a great deal of specific knowledge about the problem domain. This planning is triggered by features of the problem, which identify it as an instance of a particular kind of problem for which the expert possesses a rich network of information and strategies. The

novice may well "know" many of the specific facts and conditions in isolation, but seems not to have integrated them into a richly interrelated structure. As a result, the novice attends to the more obvious (surface) features of the problem, retrieves from memory one or more equations thought to apply to such problems, and proceeds algebraically.

Major achievements of this research have been the discovery that both experts and novices proceed consistently when working on problems and the finding that there are clear differences in knowledge and strategies associated with differences in problem-solving ability. Specific knowledge of these differences permits us to design instruction that should "close the gaps." Work by Jill Larkin and Herbert Simon at Carnegie-Mellon University has contributed considerably to such understanding. Fred Reif, a physicist from the University of California, Berkeley, is engaged in what he calls "human cognitive engineering," designed to close the gaps through particular instruction and practice.

New Knowledge for Productivity

There is a commonly perceived time lag of many years between the discovery of a scientific principle or engineering procedure and its widespread implementation into practice and into curricula of schools and universities. For the past two years NSF has been supporting projects to provide some insight into the reasons for this lag and, more important, how it might be reduced. A new project directed by John Gibson of the University of Virginia nicely illustrates the main points of this program:

- *Significant new knowledge.* Since the mid 1960s it has been known that Computer Aided Design (CAD)—combining computer-generated graphics with detailed computations—can have a major impact on the engineering of new products. A study at a major aviation company showed a return of 1,000 percent on investments in CAD, which speeded project development and increased product quality. Inexpensive microcomputers will soon make similar systems, and similar increases in productivity, available within the budget of most engineering firms. The implications for teaching are clear: Engineers will need to be trained for a radically different approach to design work.
- *Analysis of barriers.* Engineering schools have found that costs of equipment, instructional programming, and retraining of faculties limit their capacity to adapt to these new methods.
- *Development of a generalizable solution.* Since there are already major internal and industrial resources available for curriculum renewal, much progress could be made if these resources were better mobilized in, and shared between, schools. Gibson, along with an initial group of ten other deans and presidents of major engineering schools, is organizing a broad-based consortium to share the costs of preparing instructional programming and to encourage the development of educational hardware for their needs. In addition, through peer review and publication mechanisms similar to those in research, they will reward faculty who have learned the new approaches and who make substantial contributions in the form of instructional materials. If successful, the consortium will emerge as a self-sustaining group which can continue to update the curriculum in the CAD area and provide a model for curriculum improvement in other engineering areas.
- *Promotion of a lifelong knowledge-seeking and problem-solving orientation.* The project will combine design-oriented case studies and problems with computerized instructional materials, cooperative study in industry, and continuing education to emphasize the close relationship between new knowledge and ongoing productive practice.

Other projects have been exploring and developing responses to other parts of the problem of how to rapidly revitalize curricula. Examples are:

- *Appropriate technology and community colleges.* Navarro College in Corsicana, Texas, has organized an international group to develop and exchange curricula for training engineering technologists to design and maintain solar and other alternative energy installations. Among the major barriers being addressed are the wide variability of local circumstance (climate and regulations) and the need for documentation for teaching the large number of techniques required to make complex systems work.
- *Service courses.* Peter Signell of Michigan State University is directing a project on "Problem-Oriented Physics," which is reconstructing the undergraduate physics curriculum in modular, self-instructional form. In addition to a strong emphasis on problem-solving methods, the materials attempt to combine modern theoretical techniques with examples at the forefront of applied physics. The system of materials is designed to appeal to people of many different backgrounds and levels of sophistication by permitting them

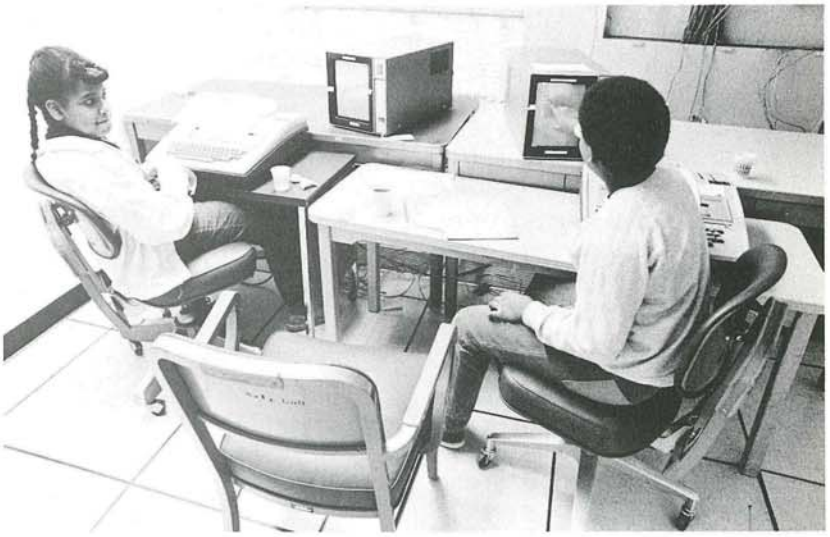
to learn, at their own rate, the physics they need to solve specific problems.

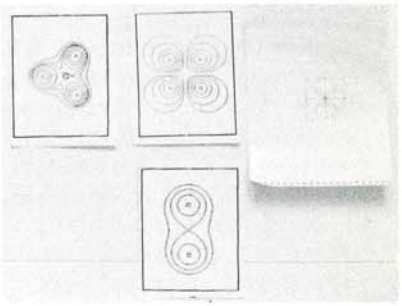
- *Academic-industrial exchanges.* Randall Sadowski and Wilber Meier of Purdue University are working with industries and university industrial and mechanical engineering departments around the country to document and disseminate the generalizable procedures behind successful computer-aided manufacturing and robotics programs. Case studies of these procedures will be analyzed to develop a curriculum and instructional materials for upper-level and continuing education. Some of the barriers they are trying to overcome are the highly fragmented and industry-specific processes used in CAM and the lack of a common set of models and theoretical approaches for students and practitioners to use in instruction and technology transfer.
- *Combining problem-solving with knowledge instruction.* Brice Carnahan, through the CACHE Corporation, a nonprofit association of chemical engineering departments and industrial associates, is exploring the use of an "engineer's personal computer" to teach design. Microcomputers will have electronic access to a library of computer programs, compilations of data, and instructional materials (prepared under prior grants) covering the content taught in undergraduate and some graduate and continuing education. The computer can simulate realistic case studies and problems for the students, compile results of lab tests of student designs, and then provide diagnostics on their problems and recommendations for which articles are available in the electronic library. The two major problems this project addresses are how to organize instruction so that it is realistic and deals with student problems, and how to arrange the rather complex programs so that many engineering professors can contribute to their construction and further development without becoming instructional specialists.

Technology for Science Education

In view of the need to improve mathematics education for school children and to take advantage of the rapidly increasing rate at which low-cost microcomputers are becoming available in schools, NSF began a special effort in 1980 to support development of prototypes of quality educational software and courseware for teaching and learning mathematics. This activity is jointly funded with the National Institute of Education and emphasizes both research and development aspects of the problem.

The projects supported address mathematics education in all the precollege grades, and several involve adults who are studying precalculus mathematics. Topics include the improvement of spatial skills (emphasizing the needs of women), problem solving, and mathematical modeling. A number of projects take advantage of the graphics capabilities of computers to involve the student in dynamic interactions as a means of visualizing a variety of algebraic and geometric concepts. Several





Software for schools. Taking part in a Massachusetts Institute of Technology project to develop ways to integrate low-cost computers into elementary school mathematics instruction, these children learn to write programs to create and modify computer displays of geometric figures.

projects call for participation of local schools, teachers, students, and parents. The students are the target population of most projects; in one, however, the primary focus is on teachers.

Examples of projects are:

- Investigators at Wittenberg University in Springfield, Ohio, will develop 10 to 15 computer games to supplement mathematics instruction in grades one to four. The games will provide practice in basic math skills—including problem solving, estimation and approximation, computation skills, and measurement—and will introduce students to problem-solving techniques. Color graphics and animation should increase student motivation and involvement. The project will involve elementary teachers in development of materials and will test the programs in public schools.
- A project at the University of Pittsburgh will do research and related development on the difficulties that children in the primary grades have in learning addition and subtraction of whole numbers. Important mathematical principles, especially place value, will be demonstrated using both physical materials and computer graphics. Student responses will be analyzed by the computer and by teachers to identify systematic errors in student computation processes. The computer will then provide meaningful instruction designed to increase student understanding of the underlying mathematical principles. The project intends to provide practical instruction, usable in classrooms at a reasonable cost, as well as an opportunity to test the validity of a developing theory of the origin of arithmetic errors and ways of preventing these errors through instruction.
- A team at Rensselaer Polytechnic Institute will develop and test materials to train students' skills in spatial visualization and orientation. The project uses the dynamic, responsive medium of computer graphics as a tool in spatial visualization and orientation training. The software will enable teachers to design new training experiences without special knowledge of computing. Since sex differences in spatial abilities have been widely reported, the project's research component will compare the changes in spatial skills shown by males and females. If the materials developed by this project are successful, they can be expected to improve mathematical performance among women and thus increase their access to careers in science and mathematics.
- A team of mathematicians, mathematics educators, and computer scientists at Drexel University will design, develop, and field-test a laboratory course in mathematics to accompany and be an integral part of a high school course on elementary functions. This laboratory component will consist of a series of "mathematical experiments" that use a microcomputer with graphics capabilities. The experiments are a carefully constructed sequence of tasks designed to probe the essence of a mathematical concept, formula, algorithm, or theorem. The project is a cooperative one involving the School District of Philadelphia.
- Many projects are supported that address the use of computing in higher education. John Hamblen of the University of Missouri, Rolla, has just completed *The Fourth Inventory of Computers in Higher Education 1976–77*. He reports that the expenditures for academic computing in higher education have more than doubled over the past decade. This year institutions of higher education will spend approximately $1 billion on academic computing; 2,163 institutions with an enrollment of 9.9 million students will provide students with access to computing. In addition to the inventory, an interpretive report examines and evaluates trends in administrative, instructional, and research uses of computing, as well as analyzes the uses of computing in minority institutions over a ten-year period.

Science and Society

Science and society programs reflect the concern of NSF and of the scientific community with the complex issues that arise out of the changing relationship between science and technology and the society in which they exist. The activities of these programs are based on the assumption that the health of both science and society requires: (1) a widespread understanding of the increasingly complicated base of science and technology underlying matters of personal choice and public policy on which citizens must make decisions; (2) mutually respectful interaction between the ethical and social values and standards of the scientific community and those of society as a whole; and (3) full and

Science museum exhibit. More than 200 species of sea life inhabit this prominently displayed living coral reef at the Smithsonian Institution's Museum of Natural History.

informed participation by scientists and other citizens in decision-making processes that involve science and technology at local, State, and regional levels.

During the past year the public understanding of science (PUOS) program has made substantial progress in improving the content and processes of communication between the scientific and the nonscientific community. Emphasis has been placed on the development of activities that are designed to reach large and particularly important audiences that are not normally ex-

Table 8*
Science and Society
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Ethics and Values in Science and Technology	19	$1.29	23	$1.26	37	$1.29
Public Understanding of Science	25	2.40	30	3.44	28	3.91
Science for Citizens	71	1.67	52	1.59	53	2.05
Total	**115**	**5.36**	**105**	**6.29**	**118**	**7.25**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

posed to much scientific and technical information. The most important of these activities is "3-2-1 Contact," a daily television program about science for 8- to 12-year-olds. Other projects also make use of the mass appeal of commercial television and radio. These include, for example, "How About," a weekly science report featuring Don Herbert that is broadcast as part of the news programs of over 130 commercial television stations, and "Star Date," a nightly astronomy program prepared by the University of Texas that is aired by over 1,000 radio stations.

The recent and rapid growth of science and technology centers and museums in this country has provided a particular target of opportunity for the PUOS program, and increased support was provided for museum activities in 1980. Science museums attracted 40 million visitors in 1979, many of them in family groups of adults as well as children, and there is evidence that this clientele includes sectors of the population that are not ordinarily reached by other means of communication. PUOS efforts have gone to reinforcing the role of science museums as focal points for informal science education in their communities. Typical grants include, for example, awards to the Franklin Institute in Philadelphia for science exhibits at shopping malls and to the Pacific Science Center in Seattle for a major environmental exhibit that has been particularly important and useful in increasing public understanding of the nature and consequences of the eruption of Mount St. Helens.

The ethics and values in science and technology (EVIST) program has continued to support projects to identify, understand, and help resolve the ethical and social dilemmas that arise in the work of scientists and engineers and in their interaction with citizens affected by their work. Two important new activities were initiated in 1980 to respond to the need to develop institutions and individuals capable of analyzing issues at stake in the field of science and values. Twelve awards were made to senior scholars in science or the humanities to enable them to spend up to one year of study in association with scholars in the opposite field, and four awards were made with the dual purpose of providing support for the continuing work of scholars already distinguished in the field of science and values and to encourage the development of new centers of teaching, research, and other activities in this field. Both of these activities are jointly reviewed and jointly supported by NSF and the National Endowment for the Humanities. The NEH also provided joint support for nearly one-half of the other awards made by the EVIST program.

The primary purpose of the science for citizens (SFC) program is to encourage new and improved ways of providing scientific and technical information and expertise to citizens and their organizations and representatives so they can better understand and participate in decisions on policy issues. The program continued to support forums, conferences, and workshops dealing with a wide variety of specific science-related issues in communities around the country; these included, for example, awards to Miles Community College for a series of public forums on weather modification in Montana, to the National Aquarium in Baltimore for workshops on hazardous materials in the Baltimore Harbor and the Chesapeake Bay, and to the Dallas Urban League for 20 community seminars and a citywide conference on the urban environment for minority citizens of Dallas. In addition, the program initiated the first awards for public service science centers, which are described later in this section.

SFC also made 25 awards to permit experienced scientists and engineers to spend up to one year in association with appropriate host organizations to bring their expertise to bear on important science-related policy issues. In 1980 these awards included, for example, grants to an earth scientist to work with the Lawrence Hall of Science at the University of California, Berkeley, on a community educational program on geological hazards, to an entomologist to work with the Ohio Environmental Council on a public information and education program dealing with environmental management policy, and to a geologist who will work with the Fort Belknap Community Council on an appraisal of the mineral resources of the Fort Belknap Indian Reservation in Montana.

"3-2-1 Contact"

"3-2-1 Contact," a daily television series about science and technology for 8- to 12-year-olds, is perhaps the single most important project in the history of NSF's public understanding of science efforts. This series, produced by the Children's Television Workshop, may have an impact on the scientific education of the Nation's children that is comparable to the impact of "Sesame Street" on their reading skills. NSF provided the principal funding to plan and establish the series, which received additional support from the Department of Education, United Technologies Corporation, the Corporation for Public Broadcasting, and Children's Television Workshop itself. "3-2-1 Contact" is intended to stimulate interest in science and provide a background of experience with scientific and technical activities and ideas. Its content, characters, and activities are directed toward the interests and understanding of children at a critical age, when they form lasting impressions and make seemingly casual decisions that can establish a lifelong interest in science and

technology or effectively preclude them from careers and understanding in these fields. For the same reasons, the series is particularly designed to encourage the interest of women and members of minority groups.

The first 65 programs were broadcast over 13 weeks during the spring of 1980 by virtually all the public television stations in the United States. They proved to be extremely popular, reaching an audience of over 23 million at-home viewers and an estimated 3 million school viewers. More than 5.4 million homes with children aged 6 to 11 and 4 million homes with children aged 12 to 17 viewed the series. In addition, over 7 million preschoolers watched the programs, as well as 6.3 million homes with no child viewers at all.

Sleuthing with science. Observation and logic help the Bloodhound Gang solve mysteries on "3-2-1 Contact," the Public Television program aimed at eight-to-twelve year olds in science. The series returned for a second year of nationwide viewing in 1980.

The form and content of "3-2-1 Contact" is based on two years of research by the staff of CTW with the assistance of educators, scientists, broadcasters, parents, teachers, curriculum designers, and over 10,000 children who responded to pilot programs. Although the series is independent of the formal educational process, it serves an important complementary role and has received an enthusiastic response from the educational community. Some 250,000 teachers' guides have been distributed, and in the fall of 1980 the program was broadcast twice each day so that it could be used for classroom purposes. The series has also attracted a good deal of international recognition. German, French, and Spanish versions are in production, and the Spanish version will be broadcast in Venezuela, Chile, Ecuador, Costa Rica, and Panama. The English version is being broadcast in the Philippines and Hong Kong as well as by the Armed Forces Radio and Television Network.

Public Service Science Centers

The initiation of support for public service science centers by the science for citizens program marks a shift of emphasis from short-term projects for improving access to scientific information and analysis of particular policy issues of community concern to longer-term projects for setting in place self-sustaining, community-based mechanisms for accomplishing SFC goals. This shift in emphasis also reflects a growing recognition of the importance of local and regional decisionmaking processes in enabling society to make effective use of scientific and technical developments. SFC activities in this field are based on three years of discussion and exploration and incorporate the results of lengthy consideration by NSF staff and advisors of the information provided by 20 planning

study awards made in 1979, and of extensive interaction with the wide variety of organizations and institutions that constitute the program's clientele.

Awards have been governed by three principal criteria: (1) evidence that scientific and technical information and expertise are both essential and available for dealing with the issues under consideration; (2) evidence that the sponsoring organization provides a credible base for the objective and unbiased consideration of issues and that all important community interests are adequately represented in the planning and execution of center activities; and (3) evidence that the need for a center is widely recognized within the community and that center activities are likely to receive continuing support after Federal funding has ended. NSF awards for this purpose are made in the form of three-year grants with a maximum of $100,000 for the first year, and they require sponsors to make a matching commitment of 20 percent of total budgets in the second year and 40 percent in the third year of center activities.

The first six awards include the following:

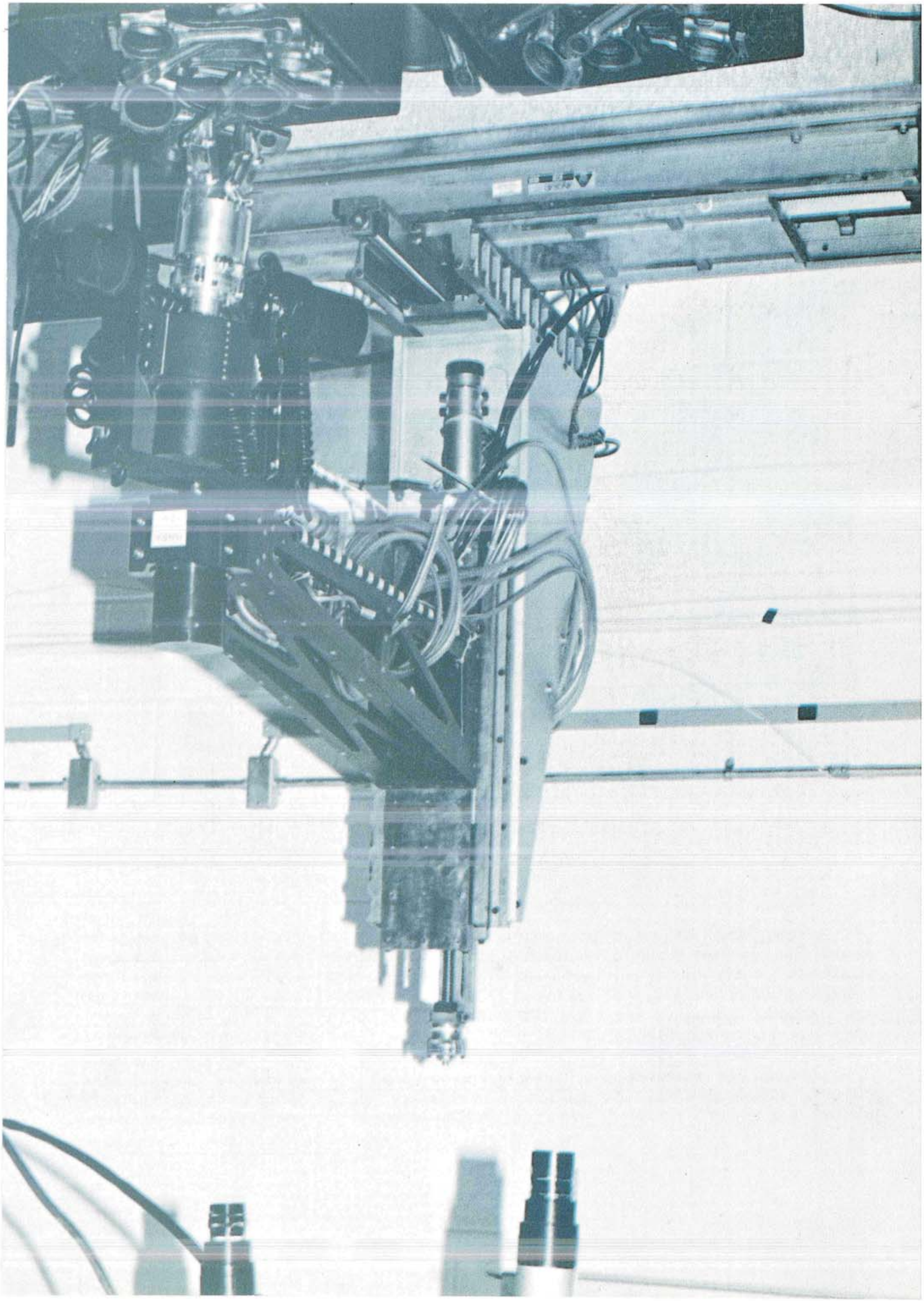
- The Montshire Museum of Science (of Hanover, New Hampshire), cooperating with the Regional Center for Educational Training and the Public Affairs Center of Dartmouth College, will develop a Public Service Science Center for the Upper Valley Region of Vermont and New Hampshire.
- The Laboratory of Architecture and Planning at Massachusetts Institute of Technology will be the base for a Boston Neighborhood Network, which will link neighborhood leaders, staff from public agencies, and researchers from MIT, Tufts, and Boston University. The Network focuses on the inner core cities of the Boston area, with an emphasis on low-income as well as minority and white ethnic communities.
- Appalachia-Science in the Public Interest, a nonprofit educational and research organization based in Livingston, Kentucky, will develop an Appalachian Technical Association to coordinate public service science programs in nine geographically dispersed centers in central Appalachia.
- The Consumer Commission for the Accreditation of Health Services, in association with a wide variety of research organizations and community groups, will develop a Consumer Health Policy and Information Center for New York City.
- The Seattle Metrocenter YMCA, in conjunction with the People Power Coalition and the social management of technology pro-

Public service science center. Local citizens in Hanover, New Hampshire, discuss wastewater treatment at a meeting sponsored by the Montshire Museum of Science and Industry. The meeting included engineers, treatment plant operators, town and State officials, and elected representatives.

gram at the University of Washington, will establish a Citizens' Center for Policy Research in Science and Technology.

- The Institute of Public Affairs at Western Michigan University, working with a broadly representative citizens' policy council, will develop a Science for Citizens Center of Southwestern Michigan designed to address the scientific and technological concerns of citizens in the 15 surrounding counties.

In addition to providing support for this initial group of centers, NSF also made a number of awards for planning studies to help communities develop comparable mechanisms supported entirely out of their own resources. Planning study grants of this kind were made to a variety of organizations and communities, including, for example, the Northwest Regional Foundation to plan a Spokane Community Resource Center and the Center for the Environment and Man in Hartford, Connecticut, to plan a technical communication network for greater Hartford.



Engineering and Applied Science 5

The Engineering and Applied Science (EAS) programs strengthen the U.S. engineering and applied science research base and enhance the links between research and applications in addressing selected national goals. They do this by identifying and supporting a broad spectrum of research and related activities with high potential for contributing to the understanding and resolution of significant societal problems.

The specific objectives of EAS are to:

- Advance basic knowledge of fundamental engineering principles that might be applied to the analysis and design of a large variety of man-made systems.
- Strengthen the academic engineering research base to address the need for more basic research underlying industrial technology and for more graduating engineers working at the forefront of research.
- Stimulate the application of fundamental scientific and engineering knowledge to the solution of significant problems in the public and private sectors, and shorten the time between scientific discoveries and their application for societal use.
- Focus U.S. scientific and technological capabilities on selected problems of national significance where NSF can make a unique contribution, such as earthquake-hazards mitigation, science and technology to aid the handicapped, and others.
- Increase fundamental scientific knowledge in selected problem areas where additional knowledge can contribute to their long-term solution.
- Provide mechanisms to increase the effectiveness of the public and private sectors in appropriately utilizing science and technology.
- Facilitate the integration of scientific and technical resources into the activities of State and local governments.
- Explore new ways to improve cooperation between universities and industry in research and industrial innovation.
- Draw upon the research capabilities of the Nation's small businesses, with a view toward moving the most promising research along the continuum to commercialization as soon as possible.

To implement these goals, EAS focuses on eight areas. Electrical, computer, and systems engineering programs cover broad areas of advanced automation, bioengineering, computer engineering, communications and information processing, microstructures, systems theory, and op-

Table 9*
Engineering and Applied Science
Fiscal Year 1979 and 1980

(Dollars in Millions)

	FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount
Electrical, Computer, and Systems Engineering	340	$17.02	349	$17.63
Chemical and Process Engineering	277	12.98	316	13.98
Civil and Environmental Engineering	132	8.15	356	9.71
Mechanical Sciences and Engineering	194	10.71	230	11.27
Applied Research	153	17.61	231	16.25
Problem-Focused Research	432	32.54	347	26.02
Intergovernmental Programs	75	5.13	50	4.51
Small Business Innovation and Industrial Technology	81	5.72	105	3.57
Total	**1,684**	**109.86**	**1,984**	**102.94**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

erations research. The program supports the National Research and Resource Facility for Submicron Structures at Cornell University, which is available to researchers throughout the Nation. The program is currently emphasizing research on microstructures, robotics and cognitive engineering systems, and investigations in large-scale systems.

Chemical and process engineering supports the development of fundamental principles, methodologies, data bases, and experimental techniques relevant to the needs of the chemical and process industry. Specific program areas are kinetics, catalysis, and reaction engineering; chemical and biochemical systems; engineering energetics; particulate and multiphase processes; and thermodynamics and mass transfer. Special emphasis is given to plasma chemistry and arc technology, combustion, particulate characterization, fluidized-bed technology, kinetics and control of catalytic and microbial processes, separation processes, thermodynamic and transport properties, and macromolecular processes.

Civil and environmental engineering increases the understanding of basic structural engineering principles and the interaction between the natural and the manmade environments. Such research helps us in modifying the physical environment wisely and safely without destroying ecological balances. Specific research areas are geotechnical engineering, structural mechanics, water resources, and environmental engineering.

Mechanical sciences and engineering develops a better understanding of the physical processes associated with power produced by various machines and engines. This understanding, along with improved mathematical formulation and advanced methodology, can provide the basis for more efficient use of power in industry. Specific research areas are fluid mechanics, heat transfer, solid mechanics, and mechanical systems.

Applied research supports 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.

Problem-focused research supports research to clarify and/or resolve societal problems by the application of science and technology. Emphasis is on earthquake hazards mitigation, alternative biological sources of materials, science and technology to aid the physically handicapped, and human nutrition.

Intergovernmental science and public technology supports the integration of scientific and technical resources into the activities of State and local governments and the testing and evaluation of incentives that the Federal Government may use to increase private R&D investment and to stimulate innovative technology in important areas of the private sector.

Electrical, Computer, and Systems Engineering

Very large-scale integration—the massing of immense numbers of electronic circuits on a microchip—continues to be one of the key technologies fueling remarkable growth in automation, communications, and information processing. In turn, the needs of the "intelligent electronics" technology drives activities in submicron structures research and computer engineering research. One impact of this drive was the establishment of a new computer engineering program during the past year.

Submicron structures research continues to make important advances at the National Research and Resource Facility for Submicron Structures located at Cornell University and available to all qualified researchers. The facility is both a fabrication resource for the academic and general research community and a research center for fabrication-related technologies. Among the significant recent research results have been the generation of intense ion beams, thin-film growth by molecular beam epitaxy, silicon-on-sapphire field-effect transistor fabrication, and integration of optical components in integrated optical circuits. Basic studies of the electronic conduction and resonance properties of very small (50-angstrom-diameter) metal particles have also been carried out. The facility is nearing full strength as major pieces of fabrication and diagnostic equipment are installed.

NSF's submicron program supports other microfabrication and small-device research as well. A notable recent accomplishment is a modeling program to characterize X-ray and other techniques for the generation and replication of device patterns. The model has been successfully used to predict pattern replication distortions that arise as a result of the presence of standing waves in near-ultraviolet optical systems. Research programs in electron-beam lithographic techniques, in plasma etching, and in modeling of small-device structures have also been initiated. Research in magnetic-bubble memory systems and in surface-acoustic-wave signal processing devices also emphasizes significant submicron and microfabrication aspects.

Communications research needs better theoretical knowledge of what topology, protocol, and dynamic architectural reconfiguration options are available and desirable for computer communication networks and in multiuser broadcast channel systems. Good fundamental investigations are in progress in this area.

In systems theory and operational sciences, recent accomplishments include improved Kalman-filtering approaches to the interpretation of geological prospecting data and formalization of the so-called reduced-order modeling of large-scale interconnected systems. In the latter topic a new concept, mutual modeling, recognizes that in many large-scale system situations, different controllers (i.e., decisionmakers) have different information about the system and hence will be using different simplified models of the same system. They may also have different performance goals. The mutual modeling approach is perceived as an iterative process in which the modeler of one subsystem communicates his simplified model to all other modelers. The others, in turn, update and improve their own models of the systems. A major research goal is to develop an analytical framework for studying the properties of this iterative modeling process.

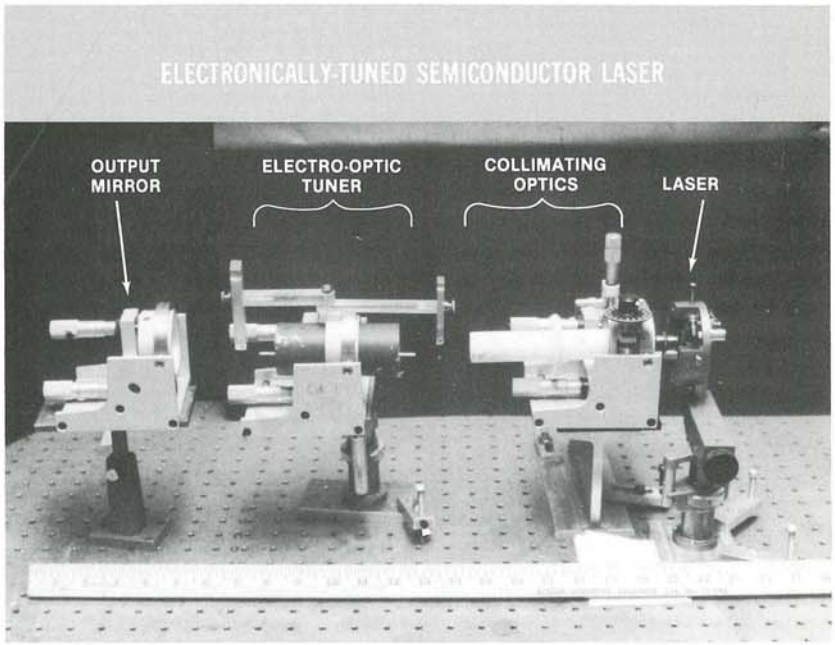
In automation, research is growing in all aspects of machine decision and control. This increased interest has been stimulated by a new generation of microcomputers and improved electronic and electromechanical components, as well as advances being made in the cognitive sciences. To capitalize on the strides that have taken place, NSF is emphasizing research in machine decision and control. Researchers are currently trying to understand how machines can perform such functions as logical inference, self-learning, vision and perception, and end-effector control. Ultimately the research will include other elements needed to create a machine that can function in a non-predictable environment by using imprecise information while adapting to a changing problem domain.

Optics in Communications and Computing

It has long been recognized that the capacity of an electromagnetic wave to carry information increases with frequency; for that reason, light waves can carry much more information than electromagnetic radiation in the lower portions of the frequency spectrum. In computing, the possibility of using light energy to make calculations at ultrahigh speeds is equally intriguing. These two important areas of research have significant implications for future communication and computing systems.

A communication system, in its simplest form, consists of a transmitter, a medium (atmosphere or a cable), and a receiver. It is now evident that systems can be made more versatile by new ways of tuning the transmitter and modulating the wave (adding the message to be transmitted) emanating from it. This is true for both optical and radio communication. Recently Chung Tang of Cornell University demonstrated rapid electronic tuning of a type of laser over a large spectral range. Called an external cavity laser, its heart is a tuner whose output light suffers minimum loss at a particular wavelength, causing the laser to oscillate at the corresponding frequency. The output wavelength of the laser can be changed by an applied electric field.

The whole device can be made in a space approximately 20 centimeters long and 3 centimeters in diameter. Although it is very large compared to a conventional semiconductor laser, it is extremely small compared to other electronically tunable lasers,



Experimental device. This 20-centimeter-long model of an electrically tunable laser is far smaller than other tunable lasers. Such a device may finally make possible a simple FM optical communications system.

such as the argon pumped-dye laser. But conventional semiconductor lasers cannot be electrically tuned either rapidly or over a large spectral range; in fact, they usually have a fixed wavelength output.

Tang believes that the tunable laser can be reduced to a form for use in integrated optical circuits, because the two basic elements of the tuner already exist, although work only marginally well, in such form. More recent work includes the investigation of a continuous output from the laser over the entire optical region—which increases twentyfold the number of channels—by eliminating reflections from the intracavity surface of the laser.

Such an electronically tunable laser source at last shows the feasibility of a simple frequency-modulated (FM) optical analog system. Much like FM communications systems at radio frequencies, an atmospheric FM optical system can be made insensitive to many disturbances in the atmosphere. An FM digital communications system that uses two different wavelengths has been devised and experimentally operated.

Interesting applications outside of communications also exist for the tunable laser. For example, sonar systems used for detection of objects underwater have low sensitivity. The tunable laser can be used as a basic source for an optical sensor in an optical fiber interferometer system. In this system the return sound signal changes the interference pattern in the interferometer; the tunable source is automatically tuned to the highest sensitivity, which produces the largest signal-to-noise ratio for the interferometric pattern. It can be expected that rapidly tunable, small-size lasers will find numerous important applications in a variety of systems.

An important recent development in optical information processing systems has come from work by Sing H. Lee of the University of California, San Diego, on the optical processing of digital information. The emphasis at the present time is to create hardware devices and systems.

Optical processors are inherently two-dimensional, capable of processing large amounts of data in parallel, for example image and picture data. The digital optical processor, when developed, will be potentially capable of high-speed, high-accuracy computation as well as increased operational flexibility.

Lee has constructed a small device consisting basically of a photoconductor and a liquid crystal arranged to bring about an interaction between the two input images. Two such devices have been interconnected using a polarizing beam-splitter and other ordinary optical components to build an adder circuit.

In the short term it is expected that the digital optical processor will be most useful in processing data in two-dimensional form. Many medical data and remotely sensed data are of this form. With the demand for image transmission expected to increase rapidly in the future, optical digital processing may be competitive. In the longer term, more sophisticated digital optical processing techniques combined with reliable and documented software will provide the basis for high-speed, high-capacity optical digital computing systems.

VLSI and Artificial Intelligence

Very large-scale integration (VLSI)—the design and manufacture of highly concentrated microcircuits—offers the real possibility for university-based computer research to play once again a major role in the engineering of computers and computing systems, similar to the situation in the late 1940s and early 1950s. Enhanced ability to design, build, test, and use novel computing structures holds the promise for revolutionizing computer engineering and science.

Areas of research such as parallel processing, multiprocessing, and natural language intelligent interfaces are experiencing renewed interest. The possibility now exists to tailor special-purpose computer architecture to the problem to be solved rather than the conventional approach, which starts with a general purpose computer and goes to language to algorithm to solution. This accounts for the strong, new research emphasis on design, analysis, implementation, and use of VLSI for novel special-purpose hardware and new computer architectures, and stress on the relationship between classes of algorithms and the hardware implementation. The ability to "write software in silicon" is breaking down the old distinction between hardware and software.

Basic research in "artificial intelligence" over the past decade and a half, coupled with advances in VLSI, has made feasible the area of knowledge engineering. In particular, knowledge-based systems—interactive software systems expert in a particular knowledge domain—have been successfully built and exhibit characteristics of intelligent systems. Applications of these systems to medical, geological, and oil data analysis are under way.

Such systems could be described as large phenomenological simulators. Serious research issues concern knowledge acquisition, representation, and utilization. To generate the knowledge base necessary for engineering future intelligent systems, research will be needed on knowledge representation, planning systems, object modeling (which includes mathematical modeling, computer representations, transformations between different representations, computational geometry, and efficient computational algorithms), very high-level languages, and programming environments.

Chemical and Process Engineering

Chemical and process engineering at NSF supports basic engineering research relevant to new technologies in a wide range of industries. Collectively known as the chemical and process industry, it includes chemical, petroleum, food, pulp/paper, biochemical/pharmaceutical, mineral, and nuclear industries.

Current primary concerns in this industry are to develop efficient chemical pathways and separation processes for the production of materials and conversion of energy. In terms of chemical pathways, resource shortages have forced the industrial sector to look for ways to use raw materials that have been heretofore largely neglected. In response to that, in 1980 NSF created two new programs—chemical and biochemical systems; and kinetics, catalysis, and reaction engineering—to replace the previous chemical processes program. This brought our catalysis research support into sharper focus while more adequately addressing basic biochemical reaction mechanisms and control strategies for microbial processes. The separate identity for biochemical engineering has resulted in a great deal of enthusiasm, not only in biochemical engineering *per se*, but also in its companion field, polymerization and polymer processing, as evidenced by the significant increase in proposal pressure in both areas.

Another pressing need, to develop fundamental knowledge in separation processes, is leading to a new NSF research program in that area. Previously, such study was supported under the thermodynamics and mass transfer and the particulate and multiphase processes programs. Separation and purification problems multiply as the variety of raw materials, chemical pathways, and products increases. Thus, case-by-case evaluation and/or experimentation no longer suffice. Instead, some fundamentally based general theories and models must be developed so that the efficiencies and energy requirements of the various types of separation processes—such as distillation, extraction, membrane transport, adsorption, and the like, or combinations thereof—can be evaluated and compared against a uniform scale. In addition to the chemical variety, the physical constituency of the systems also takes on many combinations of solids, liquids, and gases in all forms and size ranges. This adds to the challenges faced by the chemical and process engineers in designing new separation processes. However, the opportunities and potential rewards are great.

In 1980 NSF made 11 awards in chemical and process engineering as part of industrial-university cooperative research. This represented the largest amount expended by any NSF program area as a fraction of its budget. Even more significant, of the 11 grants, only 6 had funds going to the industrial participants. This means that approximately half of the industrial participants voluntarily abstained from seeking NSF funds and contributed 100 percent of the cost of their participation.

Workshops were held in two important areas for which NSF has plans for future expansion and possible major equipment investment. One was on fluidized-bed technology and the other on plasma chemistry and arc technology. In both of these workshops, academic and industrial researchers came together to discuss important research thrusts, future community needs, and the optimal strategy in allocating limited resources. Reports on the findings are widely disseminated within the research community.

Exciting research achievements in the past year included a novel electrochemical technique employed in an oxidation-reduction study at the University of Kentucky that shed new light on metallic corrosion processes and elucidated the electron transfer mechanisms occurring in fuel cell devices. Researchers at the University of Illinois applied a unique principle in making the first direct physical measurement in this country of the amount of the different nuclear reactor species produced in fission. This capability has profound implications for nuclear reactor operation and safety. At the Johns Hopkins University, significant progress was made in a recently discovered phenomenon, photonucleation, which can be used in detecting and characterizing ultralow concentrations of trace substances in the vapor phase.

Processing for Ultimate Polymer Properties

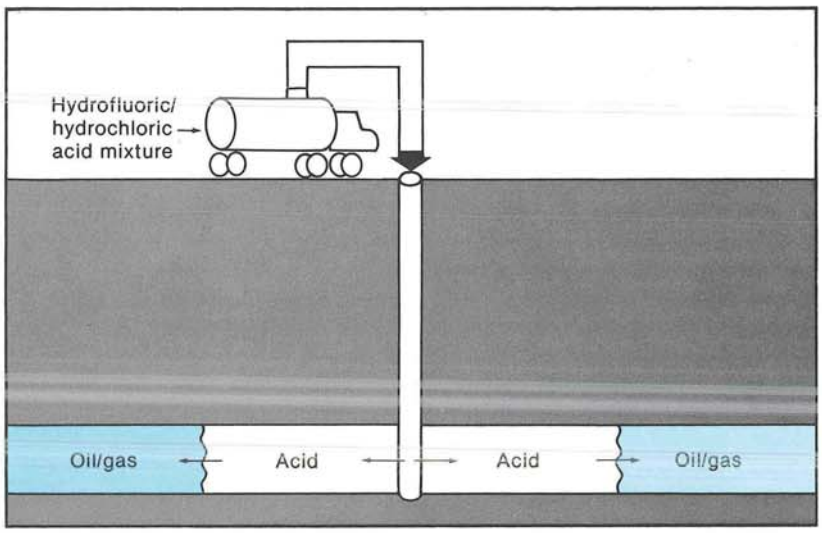
High-strength lightweight polymers are increasingly being used as substitutes for metals to conserve nonrenewable resources and energy. On a per-unit weight basis, these new materials are stronger than glass and steel. For example, organic polymers are being prepared with such tensile strengths that a ⅛-inch-diameter filament can sustain a load of almost 3,700 pounds, or the weight of an ordinary automobile.

There are two primary routes to such ultrahigh-modulus polymers. One is through polymer preparation, as exemplified by Du Pont's commercially available Kevlar. The other is by polymer processing, such as extrusion. An example of fundamental research in the latter is the pioneering study of ultradraw by solid-state extrusion under the direction of Roger S. Porter of the University of Massachusetts at Amherst. Porter and his co-workers have initially concentrated on polyethylene, the plastic

produced in largest volume worldwide. By carefully controlling the conditions for deformation below the polymer melting point, they can successfully ultradraw semicrystalline polymers. This leads to effective molecular draw and, thus, perhaps to the most anisotropic—or directionally dependent—polymers yet prepared. This property of anisotropy leads to extreme tensile moduli because mechanical loads can be borne directly on the strong polymer backbone chains that lie in the direction of draw and the direction of tensile measurement.

Porter and co-workers have proposed a "continuous crystal" model to describe certain aspects of the morphology of these polymers. They have determined that solid-state extrudates for polyethylene contain the three following morphological features: (1) crystalline blocks oriented along the microfibrils with intervening noncrystalline regions, (2) thin crystalline bridges connecting the crystalline blocks, and (3) long anisotropic crystals (longer than 1,000 angstroms in the chain direction) observed by electron microscopy and electron diffraction line-breadth analysis. This model and others are being applied to several polymers processed with a variety of drawing conditions.

These studies of ultradraw have, in turn, inspired development activities in many other laboratories. As a consequence, the Department of Energy has contracted with Battelle Laboratories in Columbus, Ohio, to prepare special electrical insulation based on structures comparable to those developed by Porter. Solid-state extrusion through tapered dies and cold rolling is being used at Battelle to make high performance insulation from polyethylene and polypropylene. The special insulation is planned initially for use on cable for superconducting magnets. The Battelle scale-up processes have lead to tensile properties ten times higher than conventional structures for the same polymers.



Stimulating production. Pumping mixtures of acids into reservoir rock can increase the porosity and ease with which oil or gas flows. Recent theoretical studies of this acidizing process have led to improved recovery of gas from storage wells.

Dissolution of Silicate Minerals

It is well known in the field of mineral exploration and mining that by pumping a reactive solution into a well in an ore deposit and withdrawing it from a second well, minerals can be recovered more cheaply and safely than by traditional mining methods. However, despite the widespread practice of injecting hydrofluoric/hydrochloric acid mixtures into sandstone formations to reduce the resistance to fluid flow, the dissolution of silicates by hydrofluoric acid is not well understood. Better understanding could have substantial impact on oil and gas extraction and solution mining.

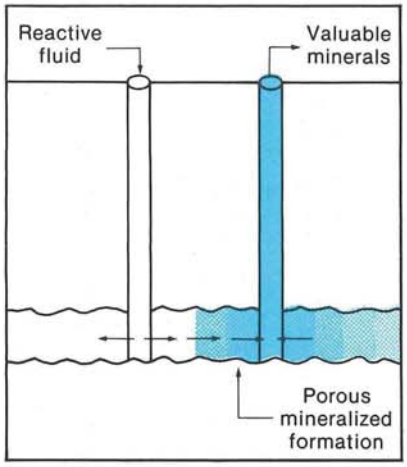
Research conducted by H. Scott Fogler of the University of Michigan aims to provide fundamental knowledge of the rates and mechanisms by which certain solid silicate minerals dissolve in water containing hydrofluoric acid. He recently developed a model that successfully describes the flow and reaction of hydrofluoric/hydrochloric acid mixtures in porous sandstones. These theoretical and experimental studies have since been used in field work for the design of successful acid stimulations of gas storage wells to increase their deliverability. Previous attempts at acidizing these wells had been unsuccessful.

Following work on the stimulation of oil and gas reservoirs, research continued on the mechanisms and rates of dissolutions of the individual minerals found in sandstone, namely feldspars (a continuous structure), kaolinite (a two-layer structure), and montmorillonite, pyrophyllite, muscovite, and talc (all three-layer structures).

One of the more exciting findings of the work is that the dissolution of a number of minerals can be catalyzed by certain species in solution which by themselves have virtually no dissolving capacity. Experiments on the catalyzed dissolution of kaolinite, quartz, feldspar, and sodium montmorillonite have shown the rates

of dissolution can be increased by as much as 900 percent. It was learned that the catalysts adsorb on the surface, thereby weakening bonds and facilitating attack by hydrofluoric acid. The dissolution of silicates can also be catalyzed by salts such as ammonium chloride, sodium chloride, and lithium chloride, as well as by strong acids. The catalysis is a strong function of acid strength. A theoretical model was developed to describe the degree of salt catalysis, and the agreement between theory and experiment is excellent.

The degree of catalysis is strongly dependent on the nature of the silicate surface. For example, the rate of dissolution of kaolinite is increased by 100 percent by the addition of ammonium chloride, while the rate of dissolution of montmorillonite is unaffected. This finding has great potential application in the area of selective dissolution within mixed mineral systems. One example of this could be in the area of solution mining of valuable minerals. Here the reactive fluid could be injected into the porous formation to selectively dissolve the desired mineral, while at the same time leaving the undesired species undissolved in the formation.



Solution mining. New knowledge of how silicate minerals may be preferentially dissolved by combinations of acids and catalysts should prove important to the solution mining of hard-to-reach valuable minerals, in which the material is chemically treated underground and then pumped out like oil.

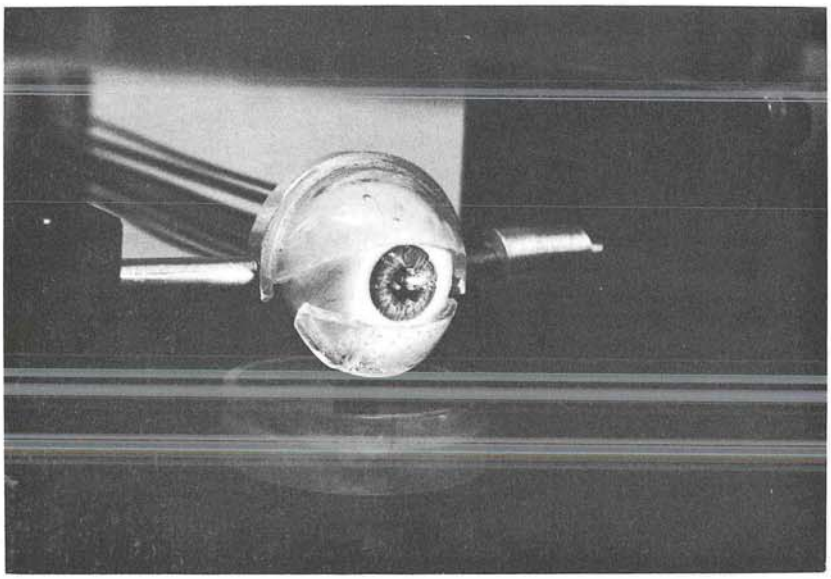
Civil and Mechanical Engineering

In 1980 NSF inaugurated a new program for mechanical systems. This new program comprises some elements, such as kinematics and acoustics, that were transferred from other programs in which they had been supported on a modest scale. Other elements represent an excursion into territory previously given only minimal coverage by NSF. These include surface phenomena such as friction, wear, and lubrication (commonly referred to as "tribology"), mechanical control systems (with special application to robotics), manufacturing operations (joining, metal forming, etc.), and automated design methodology, with eventual extension into computer-aided manufacturing.

The response of the research community to the mechanical systems program has been most encouraging. The size and enthusiasm of the response is not surprising. The program addresses itself to one of the most topical and pressing needs of American industry, that is, to the problem of sagging productivity. It is intended to form the basic arm of a multifaceted attack on this problem, in which research has been neglected over the years in comparison with other countries. Moveover, while the new program represents a response to need, it is in turn expected to enlarge the community that it serves. The outlook is extremely promising and limited only by the prospects of future funding.

Proposal pressure has mounted also in most of the other programs. The heat transfer program, whose traditional emphasis has been on problems connected with the chemical process industry, is becoming increasingly involved with energy-related issues such as geothermal energy and fuel efficiency. Currently active areas of research include liquid metal heat transfer, thermal convection, radiative properties and transport in gases, film-boiling heat transfer, two-phase thermal convection in porous media, and heat transfer in phase-change materials. Among anticipated future research areas are vapor explosion, multiphase heat transfer, sprays, and high-speed, high-temperature flows. As applies to all these engineering programs, the research is basic in character though often motivated by industrial needs.

Although mechanics as a discipline is common and fundamental to all civil and mechanical engineering, the solid mechanics and fluid mechanics programs are specifically dedicated to basic mechanics research as such. This is not to say, of course, that the results obtained are not expected to be useful, or indeed vital, to the solution of engineering problems. For example, major emphasis in solid mechanics is on the analytical and experimental determination of the behavior, for example, of metals under realistic environmental conditions involving thermal, creep, or fatigue considerations and making use of fracture mechanics, damage theory, and, of course, general continuum theory. The results of the research are likely to be needed to explain and prevent sudden failures in aircraft or nuclear power plants. Similarly, turbulence



Fluid dynamics of tears. At Case Western Reserve University, engineers use this model of the human eye to study hydrodynamic forces on a corneal contact lens after blinking.

studies in connection with bluff bodies as supported by the fluid mechanics program are expected to be useful in the design of more fuel-efficient road vehicles, and hydrodynamics is increasingly used as a tool for understanding the vital actions of fluids in biological systems.

In the area of civil engineering, NSF's largest program is in water resources and environmental engineering, which aims to develop fundamental understanding of the natural phenomena and processes in these two technical areas in terms of basic scientific principles and to model them mathematically.

The structural mechanics program, which was separated recently from the geotechnical engineering program, is currently expanding at a rapid rate. It has a widely divergent academic constituency, which ranges from research into high-strength concrete and other materials used in structural engineering to the analysis and design of plates and shells. Also included are studies of the buckling and postbuckling behavior of structures and of the response of structures to stochastic excitations as exemplified by earthquakes, wind gusts, or offshore waves. Design optimization is another major topic, including once again the possibility of environmental uncertainty. An emerging and potentially promising field is that of active structural control. In view of this diversity it is anticipated that with additional growth the program may be split into further subelements.

The area of geotechnical engineering, which was originally identified with "soil mechanics," now also includes such topics as rock mechanics, snow and ice mechanics, and in general the mechanics and treatment of all solid materials which comprise the surface and immediate subsurface of the earth. The research is fundamental in that it seeks to establish methods of determining the properties of geotechnical materials and of making best use of these materials. Because of the massive character of geotechnical formations and of engineering works, it is expected that a large centrifuge facility, funded by NSF, will play a major role in duplicating actual large-scale conditions within the confines of the laboratory.

Modeling of Wastewater Treatment Plants

Activated sludge wastewater treatment plants have been widely used for more than half a century. Their design and operation are based heavily on empiricism, and a good understanding of the dynamics of the process is missing. Yet future advances in efficiency and reliability, and ultimately the ability to use automatic control systems in activated sludge plants, depend on the availability of this knowledge.

At the University of Houston, John Andrews is developing a dynamic model of activated sludge for investigating process oxygen requirements. His specific focus is the metabolism of carbonaceous substrates, with the main emphasis on modeling the biological reactor. The experimental work has been restricted to low sludge ages (less than one day) to ensure that the effect of nitrifying organisms is negligible.

Andrews has conducted batch experiments using municipal wastewater to study the effects of particulate substrates, identify the most appropriate form of the model, and provide data for estimating the model parameters. He also developed equations for the gas-liquid interactions of a closed-reactor system and collected data from an oxygen-activated sludge pilot plant to compare with model predictions during transient loadings.

He was able to specify a best model structure for describing the biological reactions by comparing the predictions of different kinetic experiments with the batch experimental data. After model identification, the parameters for the selected model were determined using the batch experi-

mental results and a systematic procedure for state-parameter estimation.

The model for the biological reactions distinguishes between particulate and soluble substrate metabolism and considers substrate storage by the floc (chemical added to promote coagulation and settling of fine particles). The batch experimental data were best described when soluble substrate was modeled as being concurrently stored by the floc and directly channeled into synthesis pathways. For most experiments, the best fit was obtained when 70 to 80 percent of the soluble substrate was stored prior to metabolism. The particulate matter added in the batch experiments was found to have little or no effect on the total oxygen utilization rate for low sludge ages.

Simulation of the oxygen-activated sludge pilot plant indicated that the proposed model was capable of describing the transient data. The model was most applicable for predicting solids production, effluent carbonaceous total oxygen demand, and oxygen utilization. Predictions of gas phase composition and carbon dioxide-bicarbonate equilibrium were less accurate, but the general trend of predicted results appeared realistic. Most important, the model was capable of showing that the oxygen uptake rate was significantly dampened and lagged substrate removal.

Computer simulations were made to illustrate the effect of various design and operational factors on the oxygen utilization response to a diurnal substrate (soluble or particulate), the relative amounts of substrate channeled to storage products or directly into synthesis pathways, the reactor size and operational configuration, the type of separator operation, and the sludge age.

When calibrated for a particular wastewater, the proposed model can be used to simulate both air- and oxygen-activated sludge plants. Computer simulations indicated that the proposed model would be useful for properly sizing the contact and stabilization reactors. Also, because substrate removed in the contact reactor may be metabolized in the stabilization reactor, the proposed model would be useful in sizing aeration equipment. Only a model that considers substrate storage by the floc is capable of properly assessing the total oxygen requirements of the stabilization reactor.

Since oxygen requirements are usually dampened and lag the influent organic load, the proposed model can provide an improved basis for sizing conventional aeration equipment and also for sizing the oxygen-generating capacity for oxygen-activated sludge. For plants not equipped with automatic dissolved-oxygen control, improved aeration control may be possible by using the proposed model to derive a transfer function relating oxygen demand to influent flow. Also, it may be possible to utilize the model in conjunction with on-line, state-parameter estimation techniques for implementing real-time control strategies other than dissolved-oxygen control.

Strength of Solids

The widespread and unavoidable existence of inhomogeneities in materials is of major concern in their use in manufacturing, in construction, and in many energy-related problems. Inhomogeneities, which are small on a macroscopic scale (though large from an atomic point of view), almost invariably have an undesirable effect on strength and other behavior characteristics. It is important that engineers understand these effects and have access to analytical methods for taking appropriate countermeasures.

In his research at Northwestern University, Nemat-Nasser treats a material as if its inhomogeneities were actually voids. This is a valid assumption if the inhomogeneity is a fluid or solid with negligible mechanical strength in relation to the solid matrix material. When the voids are fully interconnected, the solid is granular, and Nemat-Nasser has considered a variety of behavior patterns exhibited by such material. A loose granular material such as a sand (either dry or saturated but drained) undergoes a compaction (densification) when subjected to cyclic shearing stresses. In the case of undrained saturated sand, the tendency to densify leads to an increase in pore water pressure, and therefore a reduction in the shear strength. A continuous loss of strength of this kind can lead to liquefaction, which has been observed to occur during earthquakes, during which the material slides in bulk in a shearing motion, often with catastrophic results.

When the voids are not interconnected, the resulting solid matrix forms a porous solid, which has characteristics that are both similar and dissimilar to those of a granular material. For example, the generation of voids (microcracks) in a solid gives rise to the phenomenon of dilatancy, which is observed in rocks. A related yet dissimilar phenomenon occurs in nuclear reactors as a result of radiation. Neutron radiation results in the formation and growth of voids and bubbles, causing swelling of the material and a reduction in the elastic moduli, yield stress, ultimate strength, and ductility. By modeling the radiation effect by a periodic array of voids, Nemat-Nasser was able to obtain expressions for the elastic moduli.

He has also investigated the localization of deformation in metals and geotechnical materials, an effect which is triggered by an inhomogeneity in the material. When a thin metal sheet is subjected to extension, it may lose stability by "necking" (thinning) or by the formation of shear bands. This is currently of concern to automotive engineers, as the

phenomenon is relevant to their attempt to introduce higher strength steels to permit reduction in the weight of automobiles. Similar unstable deformations exist for soils and rocks under compressive states of stress, and examples are observed in geological strata.

Nemat-Nasser has also studied the effect of the inhomogeneity that results from the interface between two homogeneous, but dissimilar, materials. It can lead to unstable deformations, and examples occur in the oriented fiber composite materials being introduced into aerospace structures and in the folding of geological formations and crustal buckling under the action of tectonic stresses.

As a final example of Nemat-Nasser's research, consider the growth of interacting tension cracks in a brittle solid. This widespread phenomenon is now being seriously studied because of its relevance to the extraction of geothermal energy from hot dry rock. The ability to extract heat from rocks that are poor heat conductors lies in the continuous propagation of thermally produced cracks in the rock. Nemat-Nasser has shown that the propagation is highly dependent on the interaction between adjacent cracks and, further, that crack propagation is governed by stability considerations. Initial progress in understanding and mathematically modeling this phenomenon has been excellent, but much remains to be accomplished before a suitable design analysis of the fracturing process can be developed.

Applied Research

The applied research program is an important element in NSF's attempt to apply knowledge developed through investments in basic research. The program's objectives are to accelerate technological innovation and expansion of basic knowledge to economically and socially significant applied problems, and to improve the knowledge base for public and private management of resources and for policymaking.

NSF responds to proposals on important applied problems in any field of science; it also selects a limited number of coherent areas relating to high-priority problems and encourages work centered on them. Currently designated coherent areas are: regulation; telecommunications; growth, income, and employment; and production research.

Applied social and behavioral sciences projects apply theoretical work in economics, psychology, sociology, political science, law, and operations research to problems such as inflation accounting, response of individuals to new technologies in the workplace, regulation, and intergovernmental finance.

Applied physical, mathematical, biological science, and engineering research applies basic work in physics, mathematics, chemistry, geology, biology, and engineering to areas such as low-grade ore processing, batch process manufacturing, and production of new crops and protein sources.

The following descriptions give an indication of the breadth of the problems addressed in these areas.

William Cooley of Terraspace, Inc., in Rockville, Maryland, is studying the problem of developing a family of tools suitable for demolition and excavation of rock in urban areas. He is completing a proof-of-concept study of the environmental acceptability of the use of the hydraulic bursting method. He first conducted laboratory research on fracture and disintegration of concrete by hydromechanical methods, then developed a system and successfully tested it in a quarry. The tests to date have shown that mechanical fracture and disintegration of concrete and rock can be accomplished safely, without adverse environmental effects, using hydraulic-powered devices.

Donald Dougall of the Tissue Culture Association, Inc., in Lake Placid, New York, is looking at the use of plant cell cultures for production of specific chemicals. His project examines the effects of acidity or alkalinity, temperature, dilution rate, and growth-limiting nutrient on the production of biomass and the plant pigment anthocyanin by carrot cells. The research has shown that when carrot cells are grown under chemostat conditions with either phosphate or ammonia as the limiting nutrient, the yield of cells obtained per unit of the limiting nutrient is different at different dilution rates of the cultures. The information obtained in this study will provide a basis for a rational choice of culture methods to be used in the production of chemicals by plant cells.

The nonferrous mining industry in the American Southwest was studied by Richard Mead and Gilbert Boren of the University of New Mexico to investigate the impact of changing technology on the generation of waterborne and airborne residuals and on the consumption of water and energy. The study focused on the copper industry and its principal byproduct, molybdenum. Nearly 85 percent of the domestic production of both metals comes from the Four Corners States of Arizona, Colorado, New Mexico, and Utah.

Mead and Boren developed detailed process information for each existing technology and for the new technologies being developed. This was then used to construct a large linear programming model of the in-

dustry. The response of the model to various levels of environmental constraint and various prices of water and energy provides data on the changes of technology that would occur under various external situations.

The study shows that the methodology used is capable of providing summaries of detailed technical information so that policymakers may study the consequences of various legislative and regulatory actions. In addition, they found:

- The current activity in building pyrometallurgical plants with new technologies cannot be attributed to their energy efficiency alone. Environmental legislation led to the introduction of these facilities, and lower energy consumption was a benefit.
- Hydrometallurgical processes are environmentally advantageous but are unable to compete economically with the proven pyrometallurgical techniques.
- It is essential to recycle water in the arid Southwest and to take steps to prevent losses to the water table. This results in greatly reduced discharges of waterborne residuals.
- The most economical method to prevent sulfur dioxide emissions is to produce sulfuric acid. The dispersed nature of the industry, the lack of major regional markets, and competition from sulfur products from oil refining have made it difficult to dispose of acid profitably.

Sanford M. Groves of the International City Management Association in Washington, D.C., has developed a methodology for evaluating the financial condition of a local government. The system—composed of 13 factors that affect financial conditions and 36 indicators that can be used to measure the factors—is now being used by localities to provide information on their financial condition. This provides a framework for analysis for city administrators, elected officials, community groups, bond-rating firms, and others interested in the community's financial well-being. The system can also be used for anticipating changes in a city's financial condition on the basis of historical trends.

Research is under way at Virginia Polytechnic Institute to demonstrate applicability of social learning principles and experimental methodology to the problem of developing guidelines for comfort standards in buildings. Richard Winnett, Ingrid Leckliter, and J. Fred Fishback conducted a field experiment to test the effectiveness of daily feedback on electricity use and of a videotape demonstrating how to adapt to cooler home temperatures. Either alone or in combination, feedback and the videotape were effective in motivating people to reduce electricity use by about 15 percent. The savings resulted from a reduction in household temperatures by about 3.5°F. The research indicates that significant savings in energy use may be attained through the use of simple behavioral techniques.

Research conducted by Anthony Oettinger of Harvard University has produced a series of reports on legal and impact analysis of various State cable television regulation policies. This information has been made widely available to State regulatory commissions, Federal officials, selected private-sector organizations with an interest in cable-TV regulation, legislative commissions, and academics interested in this area.

Harvey J. Levine of Hofstra University has produced a volume examining policy alternatives in the area of television licensing. The book, *Fact and Fancy in Television Regulation*, examines relevant regulatory goals, measures the divergence of these goals from actual license performance, explains these divergencies, and considers alternative ways to narrow or eliminate them.

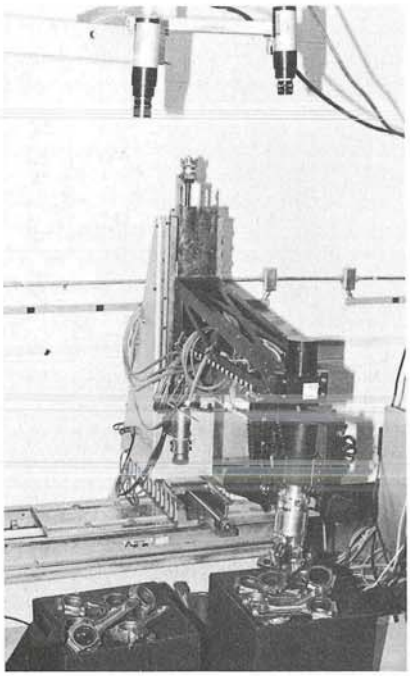
Small-claims courts are an important institution developed to provide quick, inexpensive, evenhanded, and effective resolution of smaller civil claims. This institution has been studied by John C. Ruhnka and Steven Weller of the National Center for State Courts in Williamsburg, Virginia. The investigators, after examining small-claims courts in 14 different States, concluded that small-claims courts are indeed able to resolve disputes quickly and inexpensively. The courts were especially helpful in assisting inexperienced litigants to represent themselves. On the other hand, litigants are more likely to use fee-charging attorneys where larger claims are involved, raising the costs of using small-claims courts. The investigators propose some solutions to this and other problems involved in the functioning of small-claims courts.

Most of us have had the experience of reaching into a bin of jumbled parts, selecting a particular type of part, and moving to a particular location where it is placed in a predetermined orientation. Humans do such things with a minimum of conscious thought, but it is not at all a simple operation for a robot. Still, this is a fundamental procedure for most manufacturing processes, and bin-picking robots could be used in dangerous or uncomfortable places or in jobs that are very tedious. John Birk and Robert Kelley of the University of Rhode Island have chosen to investigate the very difficult problem of how to make a robot with vision pick a part from jumbled parts in a bin, orient the part, and place it.

To pick from the bin, a scene from a television camera must be analyzed by sophisticated computer programs to allow the robot to "know" which part to pick up and what that part's orientation is. The robot hand motion must be coordinated with the

analyzed results. The robot must "recognize" the part type it is handling so that the part can be correctly placed.

Birk and Kelley have now constructed a robot with vision that picks simple parts from several bins and places them appropriately. The system is, however, much slower than a human and can be used well only with simple parts. Their research now is directed to improving the speed and the complexity of the parts that can be handled.



Out of a jumble. "Seeing" through television cameras mounted above, this experimental robot arm at the University of Rhode Island picks a part from a supply bin. The device recognizes and selects different parts from various bins, then orients and places them in the proper assembly positions.

Problem-Focused Research

Problem-focused research (PFR) concentrates on selected critical problems where advances and application of basic knowledge can contribute to their solution. High scientific content, a focus on existing or emerging nationally important problems, and a utilitarian demonstration of the value of basic research are common attributes of all PFR programs. In 1980 PFR projects were focused on the following areas: alternative biological sources of materials; earthquake hazards mitigation; human nutrition; science and technology to aid the handicapped; integrated basic research; and problem analysis.

Alternative Biological Sources of Materials

There are many potential benefits—both economic and strategic—that accompany the development of new domestic sources of critical industrial chemicals and materials from underutilized plant and microbial biomass. In 1980 NSF concentrated research support in three major areas: conversion of lignocellulosic biomass into industrial chemicals currently being derived from petrochemical feedstocks; production of useful substances from underutilized arid land plants —particularly jojoba and guayule—as substitutes for materials presently being imported from foreign countries; and use of biosaline resources, including plants and microbes, to produce chemicals and materials.

The rising price of crude oil in recent years has led to corresponding increases in the cost of all materials derived from petroleum and natural gas. Among such products are polymers and basic industrial chemicals. NSF has supported research for several years on guayule, jojoba, and several other prospectively useful but currently underutilized plants. For example, the guayule plant, a hardy shrub native to the arid regions of southwestern Texas, northern Mexico, Arizona, and California, is a source of natural rubber. And jojoba, another arid region plant, is the source of a particularly fine grade of lubricating oil.

Recently, Demetrios M. Yermanos of the University of California, Riverside, reported that he had developed a monoecious strain of jojoba—one that bears flowers with both male and female parts. In nature jojoba is dioecious, with each plant bearing either all-male or all-female flowers. There are about equal numbers of male and female plants. Development of a monoecious jojoba plant is an important factor in large-scale cultivation. Plants of both sexes must ordinarily be intermixed to assure successful commercial production of the oil-bearing seeds. But the newly developed monoecious jojoba would ensure the availability of pollen whenever the female parts of its flower are receptive and would preclude the need for wind currents or insects for pollination. In addition to these advantages, monoecious jojoba plants that originate from male ancestry—such as this new strain—have all their flowers arranged in clusters, a rare and highly desirable characteristic for a crop to be harvested.

This development climaxes several years of research by Yermanos. He first became interested in this problem when he observed a few male plants in his research nurseries that were structurally the same as other male plants but which had the tendency to produce a small number of perfect male/female flowers. These flowers appeared sporadically and infrequently, and usually all of them aborted very early in their development. During one year, however, three such flowers continued their development to maturity and yielded three poorly shaped jojoba seeds.

Arid region plant. This new strain of jojoba, which has both male and female flowers clustered on the same plant, could greatly simplify commercial cultivation. Jojoba seeds are a source of fine lubricating oil.

These seeds were carefully propagated, and persistent selection over several generations of plants has now led to the development of jojoba plants that are entirely monoecious. All the flowers produced by this new type of plant are perfect, and several oil-containing seeds are produced by each plant.

Work is already under way to propagate these monoecious plants and make them available to other researchers and botanical gardens. Although these plants represent a major advance in the production of monoecious jojoba strains, they are not yet ready to be released for commercial use. More research is needed to raise their oil productivity to levels recorded for normal female plants. Many researchers have pointed out that male plants have a faster rate of growth and are usually taller and more vigorous than female plants, but the seeds of the best natural dioecious female plants yield more oil than the seeds of the currently available monoecious plants.

According to Yermanos, this research is not only the first step in breeding improved varieties of jojoba, but should also open new areas of biological research into the genetic factors that determine sex expression in other plants.

Earthquake Hazards Mitigation

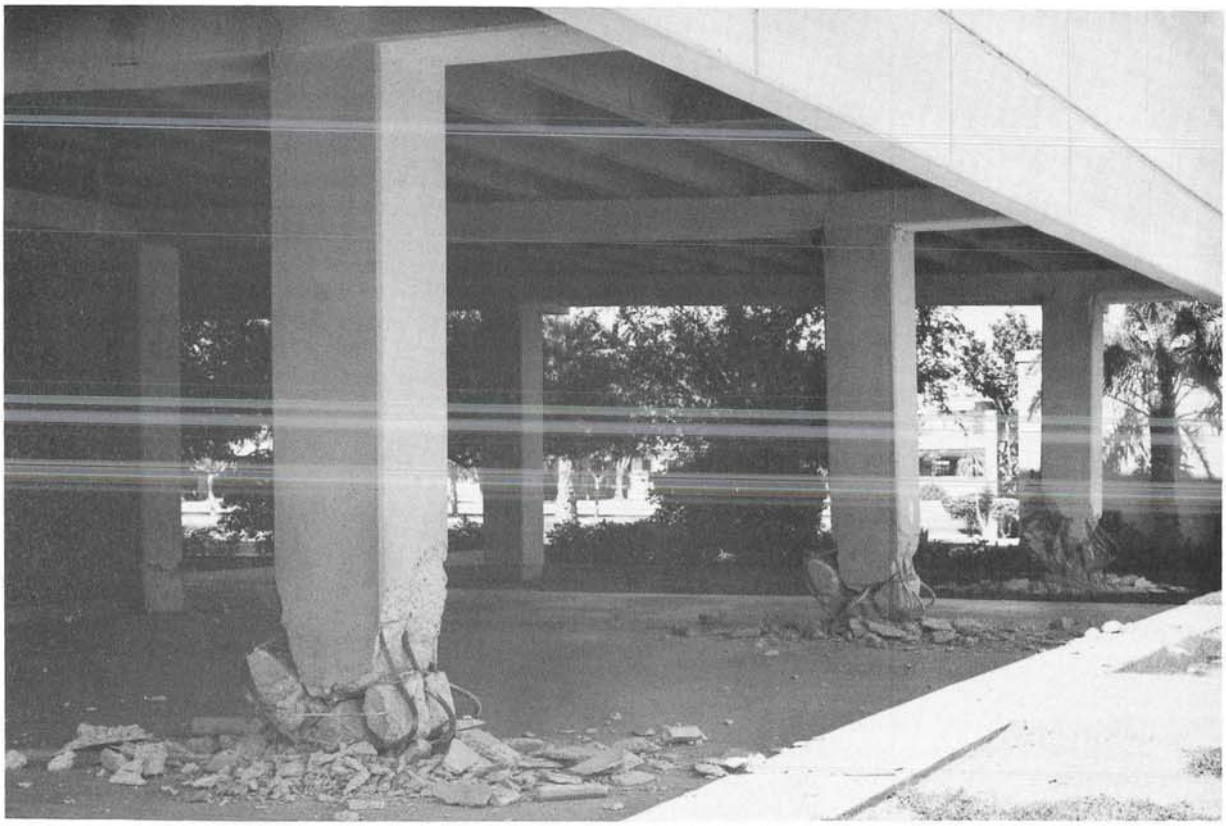
On October 15, 1979, an earthquake of magnitude 6.4 struck California's Imperial Valley region, damaging many buildings and other constructed facilities. The quake's epicenter was located near the city of El Centro. A combination of good planning and good luck enabled engineers to collect some of the best earthquake data ever recorded. These data will be used to increase our knowledge of the response and failure of buildings during earthquakes.

Because of the known relatively high seismicity of the Imperial Valley region, a number of NSF grantees, working in cooperation with groups such as the U.S. Geological Survey and engineers from the State of California, were carrying out studies or installing measurement instruments to take advantage of any quake that might occur.

One particular building, the Imperial County Services Building (ICSB) in El Centro, had been well instrumented with strong-motion seismographs in conjunction with a research project by Gerald Pardoen of the University of California, Irvine. Pardoen was attempting to determine experimentally the vibrational characteristics of the ICSB to construct a mathematical model for use in predicting the building's behavior in a simulated earthquake. While he was still sorting out his data, the October 15, 1979, earthquake occurred, causing extensive structural and nonstructural damage to the building. Four reinforced concrete support columns on the first floor failed, crushing and collapsing almost 10 inches. Resultant damage, such as cracked floor slabs, was so severe that demolition and rebuilding will probably be more cost effective than repair. Instrument readings made as the structure failed will be of great value to engineers.

Immediately after the quake, the NSF-supported Earthquake Engineering Research Institute (EERI) rushed a team of engineers, architects, and planners to El Centro to evaluate the nature and extent of damage in the region. Christopher Arnold of Building Systems Development, Inc., in a report on the nonstructural damage experienced in the ICSB and other commercial buildings, supports the belief that nonstructural damage—such as glass breakage, damage to electrical systems, damage to contents, and partition and ceiling failures—cause the most economic loss during earthquakes.

In addition to providing support for the EERI's investigative team, NSF quickly convened a meeting of researchers from universities, business, and Government to develop a



Earthquake damage. Located in California's seismically active Imperial Valley, this building was well instrumented to record the strong motions that effectively destroyed it in the October 15, 1979, earthquake. Detailed analyses of how structures respond to shaking help engineers improve seismically resistant construction.

coordinated program of research projects to utilize the data obtained from the instruments in the ICSB and the regional USGS network of seismographs. These projects are intended to contribute to the development of new methods for designing or evaluating buildings to make them more seismically resistant, or to verify or improve practices used by earthquake hazards mitigation researchers and members of the building professions.

Lawrence Selna of the University of California, Los Angeles, is analyzing Pardoen's data to determine what modifications to the ICSB's design might have enabled it to survive with less damage. In addition to the analysis of ICSB instrument records, Selna has obtained and is studying samples of the building materials used in the ICSB to determine their strength and adequacy and the forces exerted on them during the quake. He plans also to study the workmanship that went into the building. Selna intends to study possible changes in the region's Uniform Building Codes that might be necessary to prevent similar failures of other structures in the future.

George Housner of the California Institute of Technology is studying the ICSB's response records to correlate instrument readings with observable damage. Using Pardoen's data, Housner will create a mathematical model that exhibits the main characteristics of observed response. He will also correlate readings made by a seismograph located 340 feet from the ICSB with readings from instruments on the building's first floor. These readings, together with soil-excavation studies made near the ICSB and the seismograph, are intended to explain the interactions between the building's foundation and its surrounding soil.

Mete Sozen of the University of Illinois at Urbana is constructing a one-twelfth scale model of the ICSB to simulate the north-south lateral quake forces believed to have caused the most damage to the ICSB. The primary objective of Sozen's work is

to see how accurately the behavior of a full-sized building can be simulated using a scale model.

In addition to these projects, there are several others dealing with such subjects as the effects of local geology on the strong-motion seismographs' readings, the physical characteristics of the soil near the ICSB, and the earthquake performance of nonstructural items. Architects and planners are also studying the relationship of nonstructural damage patterns and occupant behavior and the implications of this relationship in terms of life protection in future earthquakes. All of these research projects will provide valuable information aimed at improving our ability to provide cost-effective earthquake protection.

Intergovernmental Program

The intergovernmental program helps State and local governments integrate scientific and technical resources into their policy formulation, administrative management, and programmatic activities. Through projects in individual jurisdictions and through a national network of local governments, NSF support enhances the roles of local and State governments in implementing Federal policy and programs and in using the Nation's scientific and technical resources, particularly those in which the Federal Government has made a significant investment.

The local government program supports the establishment of a national innovation network to provide cooperative approaches for solving common problems with scientific and technical components. The network is composed of a number of statewide and regional groups, as well as three national groups—the Urban Consortium, the Urban Technology System, and the Community Technology Initiatives Program. Both rural and urban interests are supported. At the national level the network facilitates the development of national research and development agendas relevant to local needs.

Local governments are experiencing unprecedented demands to assume decisionmaking and management responsibilities for such complex technical issues as energy, environment, and transportation. This program also emphasizes approaches to strengthen the capacity of local governments to identify their needs and ensure that research is appropriately targeted to important problems.

The State legislative branch program supports several States to demonstrate ways to improve access to, and use of, scientific and technical resources in State legislatures. Several legislative projects begun with NSF funds have been integrated into the staffing patterns of their respective legislatures, which have assumed the full costs of continuing these projects.

The executive and legislative branch programs made 15 awards during 1980 to begin implementation of the congressionally initiated State Science, Engineering, and Technology program. This program is intended to strengthen the policy-making capabilities of governors and legislatures in scientific and technological areas by providing funding that will allow them to test new mechanisms and improve existing ones. Funding for these special projects is generally expected to be made available for a two- or three-year period.

One of the key elements of the science and technology resources program is the Federal Laboratory Consortium for Technology Transfer. The consortium, with over 200 member laboratories, facilitates the use of existing science and technology resources in the solution of public and private problems. The laboratories are also a resource for units of the national network of local governments (e.g., the Community Technology Initiatives Program and the New England Innovation Group). The Federal Laboratory Consortium shares computer data bases and conducts national and regional meetings with the user communities to ensure the broadest application of new information, research results, and successful technologies.

Small Business Innovation and Industrial Technology

Small Business Innovation Research

NSF's small business innovation research program is a unique approach to Federal support of research. It is conducted in three phases, with the first two wholly funded by NSF and the third privately funded through venture capital firms or large businesses that allow the small technology-based firms to pursue commercial objectives from a common research base.

Some 179 Phase I and II awards have been made, totaling $8 million.

The first 21 Phase II awards are now nearing completion and have generated $7 million of private follow-on funding, with another $1 million expected. Employment in the 21 firms receiving Phase II awards, as a group, has more than doubled during the 3-year period since the first proposal solicitation. Most of these firms have also coupled themselves to universities in one way or another in the course of the research.

Research areas have included advanced measurement; advanced production processes; materials; deep mineral resources; industrial processes; alternative biological sources of materials; microbial fertilizers, activators, and conditioners; human nutrition; advanced marine farming; groundwater pollution; earthquake engineering; science and technology applied to the handicapped; and appropriate technology.

Industrial Technology

Industrial technology projects try to increase the investment of U.S. industry in research and development and spur the utilization of research results. The primary area of experimentation is in the coupling of academic resources to industrial needs. The objective is to design experimental arrangements that will positively influence the coupling of the longer range and more fundamental research orientation of academic science with the directed research needs of industry.

University/industry cooperative research centers aggregate the fundamental research interests of several firms, usually 6 to 20, across a given technology to fund research jointly where no single firm could capture sufficient benefits from it to justify its cost. A center normally becomes self-sustaining in 3 to 5 years. An example is the Computer-Aided Design Center at Rensselaer Polytechnic Institute, which is now in its second year of NSF funding. Ten private firms currently are cooperatively funding $180,000 on an annual basis. By the end of the fifth year the declining NSF funding will terminate, and the center is expected to become fully self-sustaining at a level of $600,000 per year with approximately 25 to 30 sponsoring companies. There are now 12 such centers at various stages of development. An additional 10 will be initiated during 1981.

Innovation centers, through their research on the innovation process, classroom instruction, and business training, provide potential and practicing technological entrepreneurs with knowledge and real-time experiences in product development and new business initiation, development, and growth. In addition, the centers may assist existing technology-based businesses that are growth-oriented with planning, marketing, and product development. Currently, there are five such centers located at universities throughout the country and, by the end of 1981, it is expected that a total of ten centers will be in either the planning or operational stage. One of the major outputs of the centers is the development of joint curricula, by business and engineering schools, on the management of technology and technological entrepreneurship.

Technology innovation projects stimulate the application of NSF-supported university research results into industrial innovations. These projects typically involve research projects potentially having a high total rate of return to society, but which cannot be entirely captured by a single company. Generally, these projects link a company (or companies) with a university to identify and close the remaining research gaps blocking the implementation of an industrial innovation. The projects, in contrast to university/industry cooperative research centers, accomplish a single, stated objective, rather than become a continuing research entity, and they also tend to be closer to the development stage of an innovation. An example is the homopolar welding research under way at the University of Texas at Austin which utilizes the development of a pulsed homopolar power source to weld continuous seams for the automobile industry and for the large cross sections of railroad rails.

Appropriate Technology

Appropriate technologies are defined as those which are decentralized, which require low capital investment, which are amenable to management by their users, which are in harmony with the environment, and which are conserving of natural resources. Following a program announcement in January 1980, 177 proposals were received and 31 awards were made. The predominant topic areas among current awards are recycling, resource recovery and conservation, small-scale industrial technology, rural revitalization, and the role and impact of appropriate technology.

Scientific, Technological, and International Affairs

Because society and Government are increasingly concerned with scientific and technical decisions, S&T policymaking is a growing focus of public debate, intense study, and new governmental initiatives. Decisionmakers find themselves weighing the economic and social costs and benefits of policy options when considering how science and technology can be brought to bear on problems of national interest. It is the purpose of NSF's programs in Scientific, Technological, and International Affairs (STIA) to provide fundamental knowledge, insight, and tools for these decisionmakers to use.

Briefly summarized, STIA activities provide resources and services for monitoring and analyzing the Nation's scientific and technological enterprise and for enhancing the benefits of S&T information exchange. The main components are policy research and analysis, science resources studies, international cooperative scientific activities, and information science and technology. Each of these programs contributes to the overall NSF responsibility within the Federal establishment of: (1) providing research on the interaction of science, technology, and public policy; (2) facilitating national and international exchange of scientific and technical information for the benefit of U.S. science; and (3) assisting in the development and implementation of U.S. foreign policy involving science and technology.

Policy research and analysis primarily assess the impacts of research and development on social and economic progress. Both short- and longer-term aspects are explored, particularly with respect to appropriate Federal roles. Short-term studies address current and emerging S&T public policy issues, while research, longer-term in nature, explores generic questions in S&T policy, the process by which policy decisions are made, and ways of making the resulting knowledge more useful to decisionmakers.

Science resources studies is NSF's ongoing program of surveys and analyses of national human and financial S&T resources. Activities include collection, analysis, and interpretation of data and, very important, the dissemination of the data and analyses to a wide audience in both the public and private sectors. These reports offer decisionmakers a reliable source of information on the size and direction of the U.S. scientific and technological enterprise.

International cooperative scientific activities strengthen science in the United States by improving international sharing of research approaches, facilities, and results. Priority is given to enhancing scientific cooperation with developed countries, particularly in Western

Table 10*
Scientific, Technological, and International Affairs
Fiscal Year 1978, 1979, and 1980

(Dollars in Millions)

	FY 1978		FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Policy Research and Analysis	88	$5.57	137	$5.46	80	$6.09
Science Resources Studies	48	2.51	52	3.07	79	3.45
Information Science and Technology	50	4.97	40	4.43	59	5.08
International Cooperative Science Activities	578	9.85	529	10.60	812	12.07
Total	**764**	**22.90**	**758**	**23.56**	**1,030**	**26.69**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

But in many firms only a few such qualified people were employed, partly as a consequence of the domination of the machinery market by a single supplier who traditionally emphasized leasing its equipment in place of selling it. Federal efforts to step up the pace of information flow about innovations to less innovative firms seem likely to founder on the inability of many of these firms to assess it accurately and routinely. More comprehensive strategies designed to change the institutional structure of the industry seem much more likely to result in an increased pace of innovation, according to this study.

Science Resources Studies

The science resources studies (SRS) program conducts surveys and analyses of the Nation's scientific and technical resources and produces several series of reports, summaries, and analyses. These publications are provided to a variety of users—including officials throughout the Federal Government, in State and local government, in educational institutions, and in industry—who develop science policy or who allocate science resources. Analysts who study the national and local science and technology resource allocation system make up another important user group.

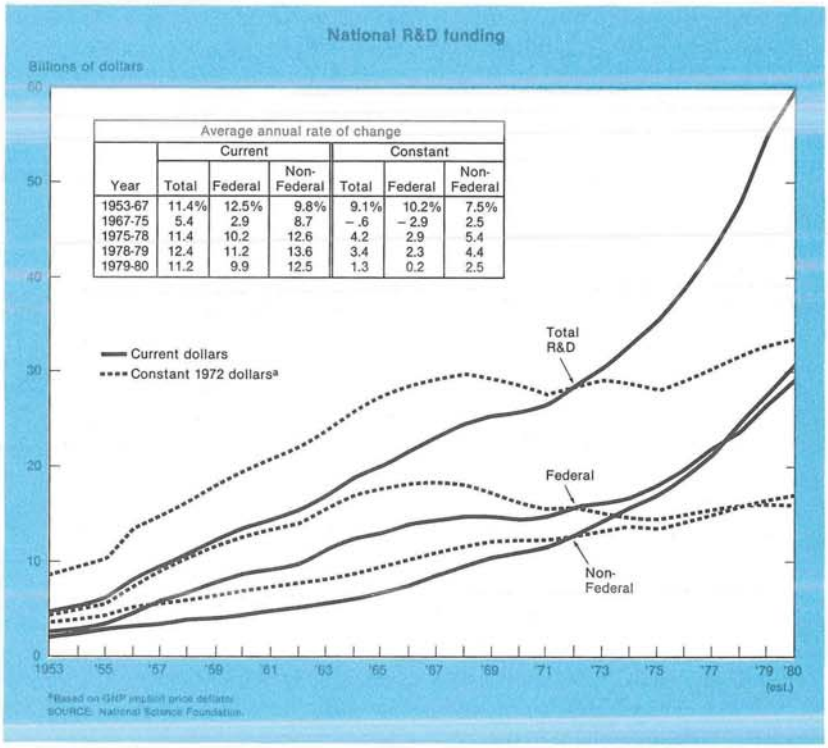
During the past year SRS has undertaken a major revision of its publications practices. The number of annual final reports on periodic surveys has been reduced from 13 to 6 by:

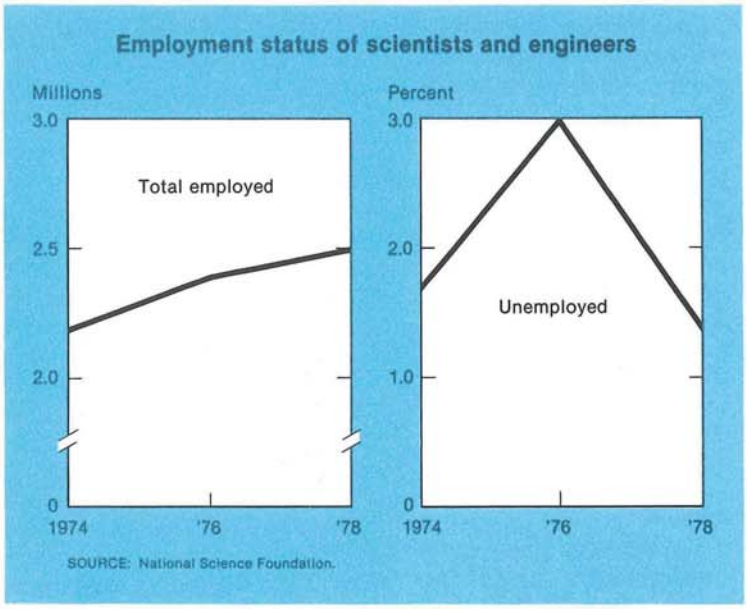
- Consolidating reports on three university and college surveys (personnel, expenditures, graduate enrollments) into a single report on academic science resources and activities.
- Replacing the former *National Patterns of R&D Resources* report with a new annual report, *National Patterns of S&T Resources*. The report will constitute an annual summary of all information generated by SRS surveys and analyses with emphasis on recent important changes.
- Combining the report *An Analysis of Federal R&D Funding by Function* with the annual *Federal Funds for Research and Development* in a single volume.
- Merging five S&T personnel reports into a single comprehensive periodic publication providing data on the supply and utilization of S&T personnel.
- Continuing annual publication of the report *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions*.
- Publishing the report *Research and Development in Industry* on a biennial basis.

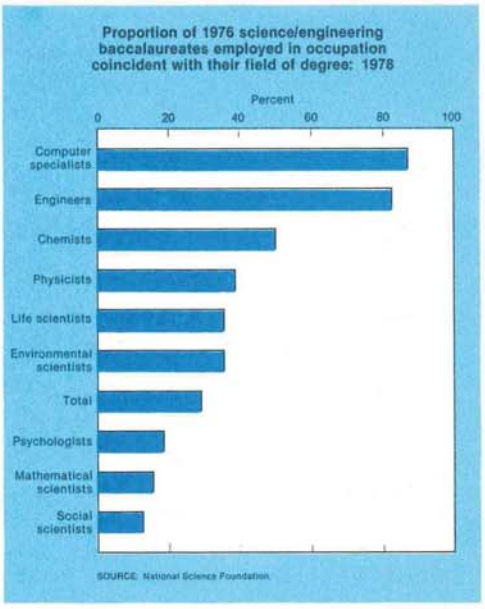
These changes should result in several advantages:

- Allow presentation of integrated national overviews.
- Provide for the first time an annual summary document dealing with S&T personnel.
- Make information more easily accessible and better integrated for the user by reducing the number of volumes to be acquired, cataloged, stored, and consulted.

The initial volume of the new series, *National Patterns of Science and Technology Resources*, was published







in the summer of 1980 and provides a concise, current overview of U.S. science and technology resources. Among the data highlights reported are the following:

- For the past four years, U.S. financial support for research and development has shown signs of renewed strength, nearly comparable to the levels recorded during the first seven years of the sixties. In constant dollars, the Nation's R&D expenditures have increased each year since 1975, for a 4-year total real growth of 18 percent. Non-Federal funding increased at almost twice the rate of Federal R&D funding. Defense, energy, and space-related R&D—representing two-fifths of the $54.3 billion R&D total in 1979—have been chiefly responsible for the recent growth in U.S. R&D activity. Inflation has been the chief damping factor in the growth of real R&D support. For 1980 the overall increase is estimated at 11 percent, or 1 percent in constant dollars using the Office of Management and Budget's inflation estimate of 10 percent.
- Total employment of scientists and engineers showed general improvement from 1976 to 1978, although these improvements were not shared equally among all fields, among all race and sex groups, at all degree levels, or in all sectors of the economy. Science and engineering (S/E) employment increased by 4 percent between 1976 and 1978, in contrast with the 8 percent rate for the total work force.
- Data indicated relatively strong demand for engineers and computer specialists. Employment in S/E occupations increased for engineers between 1976 and 1978. However, except for computer specialists and environmental scientists, S/E employment in other major fields of science fell.
- The 1978 employment experience of recent (1976) S/E baccalaureates also supports the evidence of strong employment demand in engineering and computer science. Of those with degrees in engineering and computer science, four-fifths found employment in occupations matching their degree field. In contrast, less than 15 percent of the mathematics- and social-science-degree holders found such jobs.

Information Science and Technology

Two compelling issues that seem likely to confront the Nation during the 1980s are the consequences of depletion of material and energy resources, and the opportunities provided by expanding national infor-

Cooperative research. Carl Jordan of the University of Georgia, field director for a U.S. team participating with Venezuelan, Brazilian, and West German scientists in a study of humid tropical forests, inspects nutrient flow collectors. Though lush with growth, this Amazon forest is vulnerable to disturbance, as shown by the bare patch that remains from land cleared and abandoned 30 years ago.

astronomy, physiology, and solid-state physics, along with other areas of research, but many of the projects are concerned with the biology of the moist tropics. U.S. interest in tropical ecology grew in the 1950s and 1960s, when a number of U.S. scientists traveled to Argentina, Brazil, Colombia, and neighboring countries. They made observations and brought back specimens for study in their own institutions, often with little or no participation by host-country scientists. During these same years many young South American scientists were completing advanced training in the United States and returning to their countries in positions of responsibility. Many of them felt that it would be to their own country's advantage if visiting U.S. (and other foreign) scientists were allowed access to local resources, provided that the projects involved host-country as well as U.S. participation in the planning and execution of projects. Were it not for this perception, U.S. opportunities to benefit from research in the tropics would be fewer than they are today.

The world's moist tropical forests are, in their present state, a resource with a vast potential for satisfying human needs for food, energy, structural materials, medicine, and basic scientific knowledge. But they

are being cleared away at an annual rate of almost 11 million hectares (4 million acres) as people seek fuel, food, living space, and transportation routes. Clearance hardly ever takes into account the possible social and economic benefits lost by destroying this valuable world resource or how it could be used to contribute to world stability.

One such forested region, that of the Amazon River, is part of a system that includes a sixth of the broadleafed forest area of the world. About 25 percent of the Amazonian forest has already been destroyed, and half of what remains may be gone in 15 years at the present rate. The urgency of its prudent management is evident, but in many cases we lack the necessary basic knowledge of plants, insects, mammals, and other life forms and of their interrelations. Such knowledge helps people to understand agricultural systems, to use resources wisely, to devise indicators of environmental damage, to maintain alertness against possible pathogen invasions, and to understand the nature and evolutionary relationships among plants and animals of the world.

To take just one example, several U.S. universities and other scientific organizations are cooperating with Brazilian counterpart institutions in a joint effort called Projeto Flora Amazônica. The project involves compiling data on the plants of the region that are now located in collections in Brazil and in other countries; collecting information about plants of the region and their possible uses; and intensive plant collecting in the field, with special emphasis on those areas now being cleared for new roads, farms, industrial developments, and human settlements, as well as areas of particular scientific interest. Brazilians share with U.S. scientists the responsibility for planning and carrying out the project. As a result they will have an inventory of resources and will be able to identify areas for protected reserves, establish and improve research centers, and develop training programs for their scientists. The project brings to U.S. scientific institutions large numbers of important specimens from poorly studied and threatened areas and gives U.S. botanists valuable field experience. A computer link between the two countries now facilitates the necessary exchange of information about botanical resources.

In assisting the cooperation under Projeto Flora Amazônica, NSF built on existing working relationships with the Brazilian National Research Council, carefully nurtured through joint decisions on the funding of projects in many scientific fields since 1972. NSF also heavily drew upon its experience in mutually beneficial cooperative science programs with other countries.

Cross-Directorate Programs 7

Cross-Directorate programs are those whose goals and objectives are not confined to any single field of science, but generally stretch over several. In some cases programs may be aimed toward highly focused objectives rather than toward advancing a particular field of research (such as research equipment for small colleges or linkages between industrial and academic research). In all cases the strategy is to use program flexibility to take advantage of new opportunities to improve the Nation's research capabilities.

Industry/University Cooperative Research Program

Universities are major institutions for the creation of knowledge, while industrial firms transform knowledge into useful products and services. Therefore, encouraging and strengthening the ties between industry and universities, as NSF does by supporting cooperative research in which both participate, is important to our national goal of improving the capability of industry to be innovative.

Federal efforts to strengthen these ties can use either an institutional approach or a competitive project approach. NSF's program uses the competitive project mode, in which research projects submitted to NSF compete with each other for funding. Projects consist of research in basic or applied science in which an industrial scientist and a university scientist work together directly. Criteria for project funding include both the quality of science proposed and the degree of collaboration between industry and university researchers.

To minimize administrative costs and avoid duplication of projects, peer review and technical decisions on awards are done by NSF's regular research programs, with funds provided by a separate, central allocation. Accordingly, the research proposals are peer-reviewed in competition with other proposals (cooperative and noncooperative) in the same area of science, and the peer-review procedures are no different from those for any scientific proposals received by NSF. The number of awards has been growing since the inception of the program in 1978, during which 8 projects were supported. In 1979, 57 project awards were made, and 74 were made in 1980.

Two-Year and Four-Year College Research Instrumentation Program

This past year was the first full year of operation for the new research equipment program that NSF announced on March 21, 1979. The program strengthens NSF assistance in obtaining research equipment for colleges and universities primarily engaged in teaching undergraduates. Although the relative balance between educational and research activities in these institutions is heavily weighted towards instruction, compared with the large doctoral-awarding universities, a signif-

Table 11*
Cross-Directorate Programs
Fiscal Year 1979 and 1980

(Dollars in Millions)

	FY 1979		FY 1980	
	Number of Awards	Amount	Number of Awards	Amount
Industry-University Cooperative Research	57	$5.44	74	$5.05
Special Facilities and Instrumentation Programs	55	5.61	199	7.83
Cross-Directorate International Programs	44	3.39	22	1.65
Other Programs	27	2.42	39	4.48
Total	**183**	**16.86**	**334**	**19.01**

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCE: Fiscal Years 1980, 1981 and 1982 Budgets to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables)

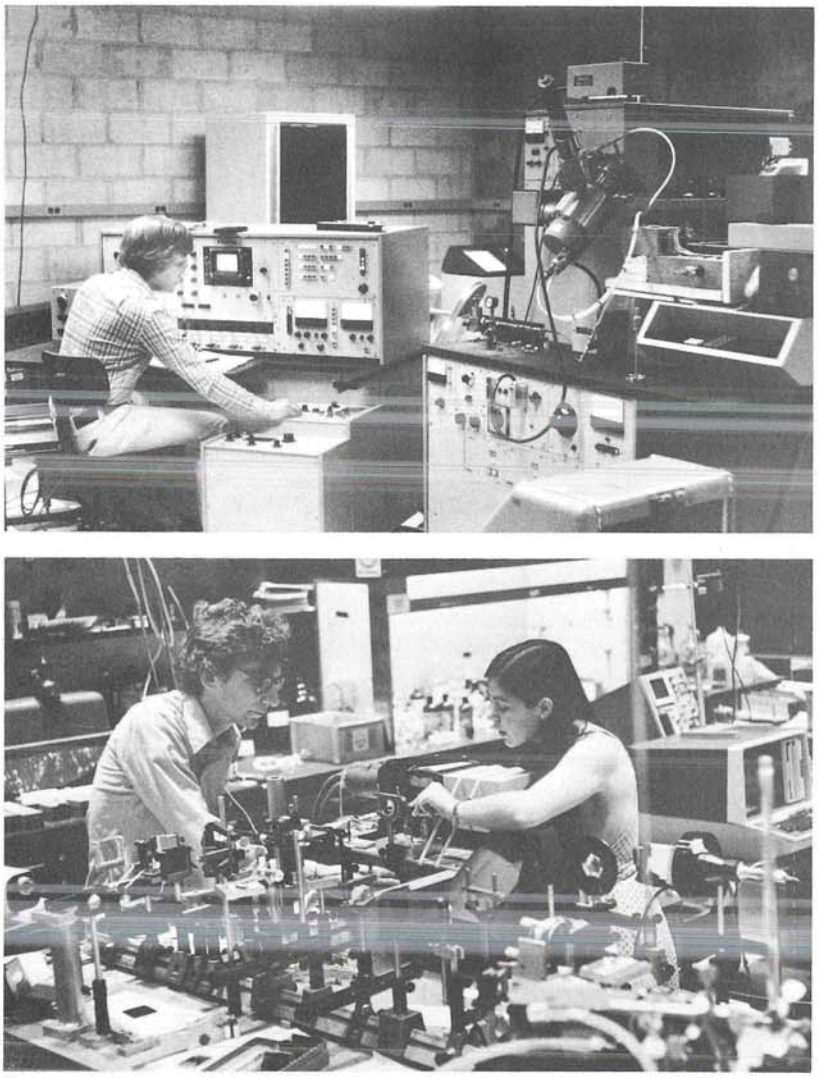
icant amount of research does nevertheless take place in many.

In recent years, too, a large number of recently trained scientists with high research capability have been joining the faculties of these institutions. In many cases their research efforts are hampered, or even completely frustrated, by a lack of research instruments or equipment. While it is rarely feasible to provide highly expensive equipment to this type of institution, many needs can be met with equipment of relatively moderate cost. In 1980 these equipment awards were limited to a maximum of $25,000, and the average award was about $18,000. Often this equipment is shared by more than one scientist, sometimes in more than one field of science, and student participation in the research projects is substantial.

The program provided support to 128 institutions in 1980. The range of sciences included astronomy, engineering, geography, geology, mathematics, computer science, linguistics, oceanography, physics, and psychology, but chemistry and biology were the most frequent users.

In chemistry, for example, a nuclear magnetic resonance spectrometer at Hope College in Holland, Michigan, is now being used by five chemists for research that includes the development of antitumor agents and studies on types of fatty acids. Thomas E. Goodwin of Hendrix College in Conway, Arkansas, is using a similar instrument for organochemical approaches to find analogs of naturally occurring anticancer compounds.

In biology, Samuel S. Kent of Lyndon State College in Lyndonville, Vermont, is using a liquid scintillation counter and other instruments for fundamental research on photosynthesis. If successful, it may lead to methods of reducing the energy needs of plants and thus the cost of producing food and fiber. Studies on basic processes of plant development by Robert W. Korn of Bellarmine College in Louisville, Kentucky, are using a scanning electron microscope made possible by this program.



Regional Instrumentation Facilities. The 14 multi-institution research centers now operating include laboratories for mass spectrometry (top) at Johns Hopkins University and for laser chemistry (bottom) at the University of Pennsylvania.

Regional Instrumentation

Regional instrumentation facilities to provide multi-institution access to state-of-the-art research equipment and techniques were initiated in 1978 with grants to 6 institutions. Eight additional facilities were established in 1979. The 14 facilities now in operation cover a variety of research interests, including nuclear magnetic resonance spectrometry, mass spectrometry, lasers, carbon-14 dating, electron microscopy, and surface science. Each facility provides creative research opportunities for a broadly based group of scientists, and a wide

variety of research disciplines are now being served—ranging from environmental science and chemistry through biochemistry and medicine to materials science. Access to the unique capabilities of each facility has benefited industrial and government scientists in addition to academic participants. It is clear that the spirit and intent of regional instrumentation facilities have only touched upon the numerous scientific opportunities that are possible, and many scientific advances, such as the following, have already come from them.

Scientists at the University of Nebraska were able to show that dioxin was not universally present in fly ash samples from coal-fired power plants at the very low detection level of 600 parts per quadrillion. Similarly, they have conducted a study, jointly with the U.S. Veterans Administration, of agent orange in tissue samples from Vietnam veterans at a detection level in the range of parts per trillion. At Johns Hopkins University polymer samples in the molecular weight range of four to five thousand Daltons have been measured through the technique of field desorption mass spectrometry. The University of South Carolina has developed a unique capability in rhodium nuclear magnetic resonance spectroscopy which has great importance in the study of catalysis. The San Francisco Laser Center has already been able to show the viability of the laser lending-library concept as a way to conduct high-risk research with lasers.

All of the regional facilities have been carefully observing each other's development to prevent duplication of research capabilities. Most facilities, in fact, have become national in scope. The facilities concept retains its freshness for the American scientific community and, for the present, most visiting scientists can be accommodated. This is rapidly changing, however, and it appears that the capacities of each facility will soon be saturated.

International Science

Two programs involving international science—those with the People's Republic of China and with the Union of Soviet Socialist Republics—reflect unique scientific opportunities and constraints and are therefore administered separately from other NSF cooperative science programs with other countries. Both offer U.S. scientists access to rare or unique research facilities, resources, and expertise through bilateral programs, joint commissions, and informal cooperation based on mutual benefit.

U.S./U.S.S.R. Cooperative Research

Under the framework of the U.S.-U.S.S.R. Agreement on Cooperation in Science and Technology, forms of cooperation range from exchange of research material and data to joint research, including periodic workshops and conferences. NSF funds U.S.-based research in several areas, including electrometallurgy and materials, physics, heat and mass transfer, corrosion, microbiology, applications of computers to management, earth sciences, polymer science, and science policy.

These programs, which take advantage of complementary research capabilities in the two countries, have made it possible for significant cost savings to be realized and for American scientists to have access to unique Soviet research personnel and equipment. For example, in a joint project on plasma-arc remelting (PAR), Battelle-Columbus Laboratories is cooperating with the E. O. Paton Electrical Welding Institute in Kiev on a comparison of the PAR process with electroslag and vacuum-arc remelting processes in the production of high-quality special steels and superalloys; PAR is a relatively new and promising technology developed in the U.S.S.R., and it is estimated that the cost of building a production/testing facility in the United States would cost approximately half a million dollars.

Cooperation in heat and mass transfer will give American specialists access to Soviet advances in this area and is expected to yield quantitative results beneficial to the United States in the design of chemical plants and industrial processes in solar, geothermal, and nuclear energy. U.S.-U.S.S.R. cooperation in theoretical physics has made it possible for some of the world's leading experts in such rapidly developing areas as relativistic astrophysics and elementary particle theory to work together intensively for the first time in many years.

U.S.-U.S.S.R. cooperation in the science policy area offers unique benefits of a different sort. The Soviet Government has given prominent attention to enhancing the management of scientific and technical research in the context of modernizing the Soviet economy. This effort has focused on the forging of more effective links between their S&T research effort and industrial production. These major institutional changes introduced in Soviet R&D management structures and procedures will have a significant impact on the Soviet Union's ability to deal with these problems in the future. Through the Science Policy Working Group, U.S. specialists have had the opportunity to obtain up-to-date information on the progress of these efforts as well as access to middle- and upper-level R&D policymakers and industrial managers who are implementing these changes. NSF is now in the process of publishing a number of studies based on this project in order to make this information readily accessible to government officials and the general public.

U.S./China Cooperation in Basic Sciences

This program will permit cooperative activities to be carried out in accordance with the U.S./China Agreement for Cooperation in Science and Technology signed on January 31, 1979. In April 1980 a delegation from NSF visited China to negotiate a program for cooperation in the basic sciences with the Chinese Academy of Sciences and the Chinese Academy of Social Sciences. General agreement was reached on the scope of such a program, though the protocol had not yet been signed by the close of the fiscal year. However, plans were laid for holding two U.S.-China Seminars in late 1980—one in natural products chemistry, the other in microelectronics. During the year NSF continued to assist the National Academy of Sciences with a program of scientific exchanges with China. In addition, NSF joined several other U.S. Government agencies in supporting the national program of student-scholar exchange with the People's Republic of China by contributing to the cost of sending U.S. students and scholars to China.

Research Initiation in Minority Institutions (RIMI)

On November 1, 1971, NSF established a program specifically to support initiation of research by faculty members associated with colleges and universities that have historically served disadvantaged ethnic minorities. The program centered on the special research needs of historically black colleges and universities and was later extended to all institutions with student enrollments that were predominantly minority (e.g., those ethnic minority groups who are significantly underrepresented in science).

This program is a long-term component of NSF's effort to provide greater access to scientific careers by minorities. It specifically deals with some of the basic problems of getting a research project started—including the need for scientific equipment, time to do the research, and means of exchanging ideas with colleagues. Proposals were accepted in all scientific disciplines supported by NSF, including applied research.

NSF made 19 awards in 1980, with an average award size of $52,400 for two years. Awards went to eight predominantly minority institutions out of an approximate total of 124 such institutions. Of the 19 awards, Howard University received six, City University of New York-City College received four, the University of Puerto Rico received three, and Lincoln University in Pennsylvania received two. Institutions receiving single awards were Chicago State University, Morehouse College, North Carolina A & T State University, and Pan American University.

One of these projects, investigating an important neuronal response to injury, may assist in gaining new knowledge on the physiological basis for recovery of motor functions after injury to the spinal cord or brain. Another of the projects, cosmological studies of neutral hydrogen, will focus on the process governing the birth of galaxies and clusters of galaxies, as well as the correlations between the neutral hydrogen, radio continuum, infrared, optical, and X-ray nuclear properties of parent galaxies and active galaxies. The ultimate goal of the study is the understanding of the galactic and immediate intergalactic environment and its bearing on the evolution and larger scale structure of the galaxy.

A third project will support a promising young solid-state experimentalist who will investigate the magnetic properties of alpha-manganese and its alloys. These materials have technological importance and are of considerable current interest to solid-state scientists.

Experimental Program to Stimulate Competitive Research

This program has been established to improve the quality of science and increase the ability of scientists in eligible States to compete successfully for Federal research funds through the accepted peer-review process. The program reflects the perception that significant national as well as local benefits are derived from participation in the national science enterprise. During 1980, grants were awarded to Arkansas, Maine, Montana, South Carolina, and West Virginia.

After an NSF-funded planning phase, a broad-based *ad hoc* committee in each of seven participating States submitted a five-year implementation plan. The implementation plans addressed impediments to excellence and were unique to each State. The committees consulted experts from out-of-state during this process so that an accurate picture of national standards in various disciplines could be ascertained. The resulting strategies included development of individuals, purchase of major research equipment, multi-institutional cooperation, and various arrangements to attract new faculty and increase incentives for research.

The funding recommendations for the implementation phase were based on a thorough peer-review process which analyzed scientific merit and feasibility of the improvement plan, and demonstrated commitment to basic research. Each State's support for this endeavor was evidenced by cost-sharing provisions, attitudes of academic and public leaders, and improvement strategies beyond the five-year duration of the grant.

Future plans for the experimental program include a formal review of all five awards after the second year of support and independent evaluation of the impact of the program. In

1981 NSF expects to initiate the planning phase in three additional States.

NSF Planning and Evaluation

Long-range planning, which provides a basis for the allocation of NSF's resources, is a cyclical process that develops and collects information on the agency's objectives, structure, current activities, and constraints and mandates. This information enables NSF to set priorities, project program activity, project staff and support needs, and identify major policy issues.

Policy issues affecting NSF or issues on which NSF is asked to take a position frequently require extensive analysis and the exploration of options for action. While much of this is done by the in-house staff, the program supports a small number of extramural studies. During the past year, contracts were awarded for:

- A study of research price indexes in different academic disciplines to better understand the effects of inflation on research in various fields.
- A study of the support of research in cryptography and its relation to national security policy.
- A study of the role of university-organized research units in academic science.
- Development of a guide for safe handling of hazardous materials in the laboratory.
- A study of certain aspects of the feasibility of solar power satellite systems.
- A study of funding acknowledgments in technical publications in a number of fields.
- A workshop on the growing role of research centers and nonfaculty researchers in academic science.

Among the earlier activities that were completed last year are:

- A study of the needs, supply, and use of scientific instrumentation and research equipment in research universities.
- A workshop on the role of organized research units for academic science at research universities.
- A study of factors affecting research vitality in the mathematical sciences.
- A study of changes in the patterns of hiring scientists and engineers at nondoctoral public colleges.

Other policy issues connected with the funding and performance of scientific activities are of continuing concern to NSF and were also the subject of discussion. Examples of such issues include the allocation of support among research areas; the relation of science and engineering to the achievement of national goals; economic and social consequences of science and engineering support; more effective mechanisms for the support of science and engineering; development of the Nation's science and engineering potential; and the opportunities for and constraints on the development of science and engineering.

Evaluation studies provide the NSF Director with information on the effectiveness of major NSF programs. They form the basis of his oversight responsibilities in these areas and provide groundwork for budgetary or policy decisions about program expansion, curtailment, or reorientation. Program evaluations are designed internally; they are often carried out by contractors.

The Senate Appropriations Committee Report No. 92-258, dated July 24, 1979, directed NSF "to implement a selected program on a pilot basis of postresearch evaluation." In response, NSF selected two areas, oceanography and chemistry, for review. The oceanography evaluation is complete, and the chemistry evaluation is in progress.

Findings of the completed oceanography evaluation are: (1) On the basis of peer review of projects, those supported by NSF were of higher quality than control projects, and NSF tends to renew proposals from better investigators. However, not all the differences were statistically significant. Much the same results were obtained from an analysis of citations and publications. (2) Postgrant ratings are more reliable and correlate better with citation and publication measures than mail review pregrant ratings. (3) NSF program directors' pregrant ratings are a better predictor of postgrant ratings than mail review pregrant ratings and correlate better with publication and citation measures.

Appendix A

National Science Board Members and NSF Staff

NATIONAL SCIENCE BOARD

Terms Expire May 10, 1982

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Herbert D. Doan (*Vice Chairman*, National Science Board), *Chairman*, Doan Resources Corporation, Midland, Michigan.
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Joseph M. Pettit, *President*, Georgia Institute of Technology, Atlanta, Georgia.
Alexander Rich, *Sedgwick Professor of Biophysics*, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Terms Expire May 10, 1984

Lewis M. Branscomb (*Chairman*, National Science Board), *Vice President* and *Chief Scientist*, International Business Machines, Inc., Armonk, New York.
Eugene H. Cota-Robles, *Professor of Biology*, Biology Board of Studies, Thimann Laboratories, University of California, Santa Cruz, California.
Ernestine Friedl, *Dean of Arts and Sciences and Trinity College*, and *Professor of Anthropology*, Duke University, Durham, North Carolina.
Michael Kasha, *Distinguished Professor of Physical Chemistry*, and in the Institute of Molecular Biophysics, The Florida State University, Tallahassee, Florida.
Walter E. Massey, *Director*, Argonne National Laboratory, Argonne, Illinois.
David V. Ragone, *President*, Case Western Reserve University, Cleveland, Ohio.
Edwin E. Salpeter, *J. G. White Professor of Physical Sciences*, Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, New York.
Charles P. Slichter, *Professor of Physics* and in the Center for Advanced Study, Loomis Laboratory of Physics, University of Illinois, Urbana, Illinois.

Terms Expire May 10, 1986

Peter T. Flawn, *President*, University of Texas, Austin, Texas.
Mary L. Good, *Boyd Professor of Materials Science*, Louisiana State University, Baton Rouge, Louisiana.
Peter D. Lax, *Director*, Courant Institute of Mathematical Sciences, New York University, New York, New York.
Homer A. Neal, *Dean of Research and Graduate Development* and *Professor of Physics*, Indiana University, Bloomington, Indiana.
Mary Jane Osborn, *Professor of Microbiology*, University of Connecticut Health Center, Farmington, Connecticut.
Donald B. Rice, Jr., *President*, The Rand Corporation, Santa Monica, California.
Stuart A. Rice, *Frank P. Hixon Distinguished Service Professor of Chemistry*, James Franck Institute, University of Chicago, Chicago, Illinois.
(One Vacancy)

Member Ex Officio

John B. Slaughter (Chairman, Executive Committee), *Director*, National Science Foundation.

Vernice Anderson, *Executive Secretary*, National Science Board, National Science Foundation.

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Head, Budget Office, Thomas M. Ryan
Acting Head, Programming Office, Syl McNinch, Jr.
Director, Division of Strategic Planning and Analysis, Irwin M. Pikus
Head, Planning and Policy Analysis Office, Irwin M. Pikus
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Head, Audit Office, Robert Boyden
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Director, Division of Information Systems, Constance McLindon
Director, Division of Personnel and Management, Fred K. Murakami
Director, Health Service, James W. Long, M.D.

Appendix B

*Financial Report for Fiscal Year 1980**

(In Thousands of Dollars)

Research and Related Activities Appropriation		
Fund Availability		
Fiscal year 1980 appropriation	$906,050	
Rescinded (Public Law 96-304)	−2,167	
Transferred to Department of Education	− 90	
Fiscal year 1980 appropriation adjusted		$903,793
Unobligated balance brought forward	$3,340	
Adjustments to prior year accounts	4,369	
Fiscal year 1980 availability		$911,502
Obligations		
Mathematical and Physical Sciences:		
Mathematical Sciences	$24,904	
Computer Research	18,397	
Physics	63,209	
Chemistry	51,303	
Materials Research	68,522	
Subtotal, Mathematical and Physical Sciences		$226,335
Astronomical, Atmospheric, Earth, and Ocean Sciences:		
Astronomical Sciences	$56,668	
Atmospheric Sciences	63,271	
Earth Sciences	25,476	
Ocean Sciences	66,308	
Arctic Research Program	5,825	
Subtotal, Astronomical, Atmospheric, Earth, and Ocean Sciences		$217,548
U.S. Antarctic Program		$55,836
Ocean Drilling Programs		$19,473

* Table displays program activities as they existed in FY 1980, prior to the recent reorganization of Foundation activities.

SOURCES: Fiscal Year 1982 Supplementary Budget Schedules, Fiscal Year 1982 Budget to Congress, and NSF accounting records.

Biological, Behavioral, and Social Sciences:		
Physiology, Cellular, and Molecular Biology	$67,198	
Behavioral and Neural Sciences	35,392	
Social and Economic Science	26,641	
Environmental Biology	37,787	
Subtotal, Biological, Behavioral, and Social Sciences		$167,018
Engineering and Applied Science:		
Electrical, Computer and Systems Engineering	$17,627	
Chemical and Process Engineering	13,979	
Civil and Environmental Engineering	9,713	
Mechanical Sciences and Engineering	11,266	
Applied Research	16,246	
Problem-Focused Research	26,017	
Intergovernmental Programs	4,515	
Small Business Innovation and Industrial Technology	3,574	
Subtotal, Engineering and Applied Science		$102,937
Scientific, Technological, and International Affairs:		
International Cooperative Scientific Activities	$12,073	
Policy Research and Analysis	6,086	
Science Resources Studies	3,448	
Information Science and Technology	5,082	
Subtotal, Scientific, Technological, and International Affairs		$26,689
Cross-Directorate Programs:		
Industry/University Cooperative Research	$5,050	
Special Facilities and Instrumentation Programs	7,824	
Cross-Directorate International Programs	1,653	
Other Programs	4,480	
Subtotal, Cross-Directorate Programs		$19,007
Program Development and Management		$58,237
Subtotal, obligations		$893,080
Unobligated balance carried forward		$1,494
Administration deferrals		$16,000
Unobligated balance lapsing		$928
Total, fiscal year 1980 availability for Research and Related Activities		$911,502

Science Education Activities Appropriation
Fund Availability

Fiscal year 1980 appropriation	$84,700	
Rescinded (Public Law 96-304)	−2,500	
Transferred to Department of Education	−4,961	
Fiscal year 1980 availability		$77,239

Obligations

Science Education Activities:		
Scientific Personnel Improvement	$33,095	
Science Education Resources Improvement	23,058	
Science Education Development and Research	13,787	
Science and Society	7,250	
Subtotal, obligations		$77,190
Unobligated balance lapsing		$49
Total, fiscal year 1980 availability for Science Education Activities		$77,239

Special Foreign Currency Appropriation

Fund Availability

Fiscal year 1980 appropriation	$5,500	
Unobligated balance brought forward	3	
Adjustment to prior year accounts	50	
Fiscal year 1980 availability		$5,553

Obligations

Special Foreign Currency Program:		
Research and Related Activities	$4,260	
Science Information	600	
Subtotal, obligations		$4,860
Unobligated balance carried forward		640
Unobligated balance lapsing		53
Total, fiscal year 1980 availability for Special Foreign Currency Program		$5,553

Trust Fund

Fund Availability

Unobligated balance brought forward	$2,448	
Receipts from non-Federal sources	4,211	
Fiscal year 1980 availability		$6,659

Obligations

Astronomical, Atmospheric, Earth, and Ocean Sciences Activity (Ocean Sediment Coring Program)	$3,632	
Gifts and Donations	11	
Subtotal, obligations		$3,643
Unobligated balance carried forward		$3,016
Total, fiscal year 1980 availability for trust fund		$6,659

Appendix C

Patents and Inventions Resulting from Activities Supported by the National Science Foundation

During fiscal year 1980, NSF received 107 invention disclosures and made rights determinations on 70 of those inventions. The determinations, made in accordance with NSF Patent Regulations, included decisions to dedicate the invention to the public through publication in 9 cases and to permit retention of rights by the grantee or inventor in 61 instances. At the end of the fiscal year NSF had entered into 3 additional Institutional Patent Agreements for a total of 29. Licenses were received by NSF under 48 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 National Science Foundation:

Number	Title	Institution
4,153,978	Method for Fiber Alignment Using Fluid-Dynamic Forces	Georgia Institute of Technology Research Institute
4,160,069	Improved Conductive and Corrosion Resistant Container	University of Utah
4,161,814	Tunnel Injection of Minority Carriers in Semiconductors	Cornell Research Foundation, Inc.
4,173,689	Synthetic Polymer Prosthesis Material	University of Utah
4,174,907	Fluid Mixing Apparatus	Massachusetts Institute of Technology
4,175,871	Fluid Mixing Apparatus	Massachusetts Institute of Technology
4,176,329	Tone Control Circuit	Massachusetts Institute of Technology
4,178,210	Acellular Synthesis of Cephalosporins	Massachusetts Institute of Technology
4,180,935	Hydrofoil Trawl Door	Massachusetts Institute of Technology
4,181,902	Fluxon Oscillators Utilizing a Ring-Shaped Josephson Junction	Wisconsin Alumni Research Foundation
4,186,045	Method of Epitaxial Growth Employing Electromigration	Massachusetts Institute of Technology
4,188,185	Method and Apparatus for the Treatment of Particulate Materials	Massachusetts Institute of Technology
4,189,534	Cell Culture Microcarriers	Massachusetts Institute of Technology
4,196,133	24, 24-Difluoro-25-Hydroxycholecalciferol	Wisconsin Alumni Research Foundation
4,197,419	Tantalum Catalysts or Catalyst Precursors	Massachusetts Institute of Technology
4,200,821	Relativistic Electron Beam Cross-field Device	Massachusetts Institute of Technology
4,200,863	Weighted Capacitor Analog/Digital Converting Apparatus and Method	The Regents of the University of California
4,201,881	24,24-Difluoro-la,25-Dihydroxycholecalciferol	Wisconsin Alumni Research Foundation
4,202,041	Dynamically Variable Keyboard Terminal	Massachusetts Institute of Technology
4,202,051	Digital Data Enciphering and Deciphering Circuit and Method	Wisconsin Alumni Research Foundation
4,204,225	Real-time Digital X-ray Subtraction Imaging	Wisconsin Alumni Research Foundation
4,204,226	Real-time Digital X-ray Interval Difference Imaging	Wisconsin Alumni Research Foundation
4,205,983	Process for Forming Metal Compositions Containing Cellular In Situ Composites	Massachusetts Institute of Technology
4,217,113	Aluminum Oxide-Containing Metal Compositions and Cutting Tool Made Therefrom	Massachusetts Institute of Technology

Appendix D

Advisory Committees and Panels

OFFICE OF THE DIRECTOR

The Alan T. Waterman Award Committee

Terms Expire May 31, 1981

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Professor of Zoology
Arizona State University

Charles L. Drake
Professor of Geology
Dartmouth College

Willis H. Flygare
Professor of Chemistry
University of Illinois

Peter H. Raven
Director, Missouri Botanical Garden
St. Louis, Missouri

Terms Expire May 31, 1982

Kenneth J. Arrow
Professor of Economics
Stanford University

Mildred S. Dresselhaus
Professor of Electrical Engineering
Massachusetts Institute of Technology

Mark Kac
Professor of Mathematics
Rockefeller University

Frank H. Westheimer
Professor of Chemistry
Harvard University

Terms Expire May 31, 1983

William J. McGill
Muir College
University of California, San Diego

Edward M. Purcell
Professor of Physics
Harvard University

James D. Watson
Director
Cold Spring Harbor Laboratory

Ex Officio

Lewis M. Branscomb
Chairman
National Science Board

Philip Handler
President
National Academy of Sciences

Courtland D. Perkins
President
National Academy of Engineering

John B. Slaughter
Director
National Science Foundation

President's Committee on the National Medal of Science

Terms Expire December 31, 1980

Carl Djerassi
Professor of Chemistry
Stanford University

Calvin C. Moore
Professor of Mathematics
University of California, Berkeley

Dorothy M. Simon
AVCO Corporation
Greenwich, Connecticut

John R. Whinnery
Professor of Electrical Engineering
University of California, Berkeley

Terms Expire December 31, 1981

W. Dale Compton
Ford Motor Company
Dearborn, Michigan

Mary Lowe Good
Boyd Professor of Materials Science
Louisiana State University

Leon Max Lederman
Director, Fermi Laboratory
Batavia, Illinois

Ex Officio

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President
National Academy of Sciences

Frank Press
Science and Technology Adviser to the President, and Director
Office of Science and Technology Policy

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The Christian Science Monitor

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Little Rock, Arkansas

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California Institute of Technology

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Consumer Action Now's Council on Environmental Alternatives

Joseph E. Rowe
Vice President-Technology
Harris Corporation

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Dean, School of Humanities and Sciences
Stanford University

Gilbert Sanchez
Dean of Research
Eastern New Mexico University

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Professor of Chemistry
University of Wyoming

Eileen F. Serene
Assistant Professor of Philosophy
Yale University

Harold R. Sims
President
Sims International Limited, and Sims and Associates

Constance P. Tate
Coordinator of Science
Baltimore City Public School System

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Pan-American University

Claire Bailey
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Florida Junior College, Jacksonville

James H. Barrow, Jr.
Department of Biology
Hiram College

Larry K. Blair
Department of Chemistry
Berea College

Jeffrey S. Bland
Department of Chemistry
University of Puget Sound

Mac A. Callaham
Department of Biology
North Georgia College

Mary Campbell
Department of Chemistry
Mt. Holyoke College

Frank Child
Department of Biology
Trinity College

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York College of Pennsylvania

Wilbur B. Clarke
Department of Chemistry
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