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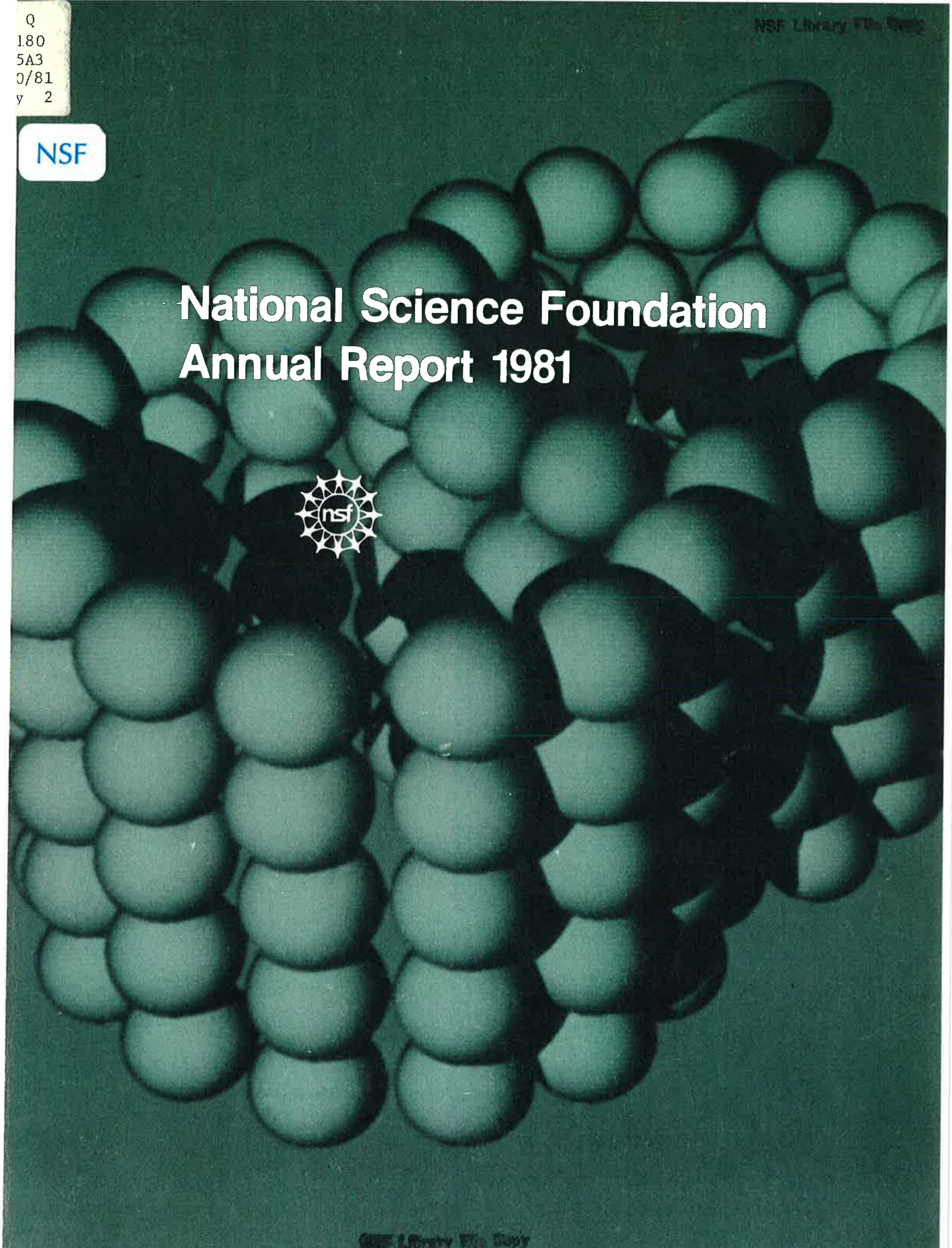
National Science Foundation Annual Report 1981



Cover: Computer-generated picture of a molecular structure (page 76)

National Science Foundation

Thirty-First Annual Report for Fiscal Year 1981

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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 1981 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

Contents

A Decade of Possibilities

JOHN B. SLAUGHTER
Director

Once again, with our annual report, we at the National Science Foundation have an opportunity to look back on the past year's accomplishments. We note with satisfaction and pride the advances in science and engineering reported here, but we do not let those successes distract us from the challenges we see ahead in this decade.

There is good reason for optimism. Certainly our scientific enterprise has tremendous momentum; convincing evidence can be seen in the remarkable speed with which new knowledge affects our society. Consider just two of the most dramatic and far-reaching developments in science and technology in recent years. One is the information revolution, the other a new understanding and application of biological processes.

The appearance a decade ago of the microscopic circuit etched on a silicon chip moved data processing into virtually every corner of our lives. Today we encounter these tiny, clever chips at the supermarket checkout counter, under the hood of our automobile, at the bank, hospital, library, office, and of course in the pocket calculator.

Why this rapid proliferation? The answer is the ability of designers to pack more and more electronics onto these tiny chips. They are rapidly overtaking the information-processing power of large computers but will cost only a fraction as much.

The result? Smarter and more versatile instruments, tools, appliances, and factory robots, as well as a new generation of small home and office computers with awesome power to handle information. It is hardly surprising to hear forecasts that one in every four American homes will have its own computer by 1990, that the office of the future will be no larger than a brief-case, and that electronic mail is just around the corner.

While we are already well into the information revolution, the impact of the biological revolution is just beginning to make itself felt. Two techniques in hand now will have major impact: the use of recombinant DNA to transfer genes between organisms, and the even-newer development of cells that can produce pure human antibodies. Both of these techniques are a direct outgrowth of basic research in molecular and cellular biology.

We see the fruits of biological research entering the commercial marketplace: interferon, insulin, human growth hormone, and a variety of other products on the horizon. Few applications of fundamental research have come so swiftly or offer such broad promise. There are also some indications that we may find comparable benefits in the field of agriculture. For example, we may be able to transport desirable new genes—such as those for disease resistance or higher protein production—into plant cells.

Meanwhile, a discovery made just six years ago—something called a hybridoma—is already on the verge of creating a spectacular new industry. Hybridomas are laboratory-produced cells that can manufacture vast quantities of specific types of antibodies. Never before available in quantity, these pure antibodies give us the ability to seek out and react with specific human cells. The potential for early disease diagnosis, targeting of highly specific medicines, and production of drugs is staggering. Two years ago, fewer than 10 companies were conducting research in this field; today there are 70.

Other successes

These admittedly awesome advances, while galvanized by a few culminating "breakthrough" experiments, are nonetheless built on thousands of individual research projects done over many years. NSF's primary goal is to identify and support projects, year in and year out, that push at the frontiers of knowledge and so pave the way for the "sudden successes." This annual report includes many descriptions of the kinds of research results that maintain this progress in U.S. science and engineering. A few examples:

- Development of mathematical models to explain how cells organize into organisms.
- The discovery of several excited states of a new particle of matter, thought to contain the fifth quark.
- Production of tiny, hollow vesicles that can carry medication and other substances to target sites in an organ.
- A fast, new energy-efficient welding process that may be a boon for the railroads and other industries in the near future.
- Identification of four galaxies 10 billion light-years distant—the furthest yet discovered.
- Work with a new sea-floor corer that is revolutionizing our knowledge of ancient climates and conditions on earth.
- Research building on the concept of plate tectonics. We now know more about modern earthquake hazards and ancient collisions that built mountain belts.
- Observations at the South Pole that give new information on the sun's interior. Polar researchers also discovered a swarm of krill several square miles in extent—probably the largest school of marine animals ever measured.

Problems—and possible solutions

With all that work to be proud of, what are those challenges I mentioned? And how do we expect to meet them?

First, our universities are under great pressure. Total undergraduate enrollments are expected to drop by perhaps 20 percent over the next 15 years because of the decline in births in the 1960s and 1970s. And inflation drives up operating costs at a time of declining income from tuition.

True, there is a big demand for many science and engineering studies. But undergraduates in these disciplines find faculties overtaxed by their teaching loads and laboratories with outdated equipment and instruments. Many academic jobs in computer science and engineering used to be coveted but now remain vacant. And there is serious concern now about producing tomorrow's high-quality science and engineering Ph.D.'s to staff our university faculties.

The strains now showing in university science and engineering departments are troubling, but they also present a new opportunity for developing links between academia and industry. One potential of university-industry cooperation may arise from the loan of industry scientists to universities to serve as adjunct and visiting professors and from the close collaboration of industry and university investigators on research projects.

Still, the great bulk of industry's research must take place in areas promising near-term application. It would be unreasonable to expect industry to be engaged in the full range of fundamental inquiry now going forward in our universities. Support for this kind of frontier research on the outer margins of our knowledge must remain the concern of organizations like the National Science Foundation.

Another critical issue is the lack of preparation in science and mathematics in our secondary schools. Few high school students in this country are exposed to more than a single year of algebra and geometry and one year of science. They are thus ill prepared to pursue college-level studies in the sciences and engineering. This problem is so widespread and diffuse that addressing it means a fundamental change in perception by state legislatures that set minimum educational standards, by school boards planning curricula for local public schools, and by universities in determining their admission requirements.

We also need more women and minority scientists and engineers. Because of their longstanding minimal involvement, our country has wasted incredible amounts of talent and is just now beginning to tap that resource. We finally see a significant increase in the numbers of young women pursuing scientific and technological careers, but our progress in opening these professions to racial minorities has been slower. Even today, Blacks, Hispanics, and other groups are only 4 percent of the field—and half of that if we set aside the high levels of participation by Asian-Americans.

I hope that we will not ignore this problem while we grapple with other difficulties in science and engineering. Both industry and universities should be thinking about how we can keep up momentum in opening these professions to women and minorities, and it must remain a paramount concern for our elementary and secondary schools too.

Public attitudes

As scientific knowledge expands, new policy options emerge, and we are presented with ranges of choices as to how and even whether to proceed. Ideally, an informed citizenry in a free society should participate fully in making these choices. Unfortunately, most of our citizens see themselves as too poorly informed about science to do that.

This conclusion comes from a recent survey on public attitudes toward science and technology. It was done for the National Science Board, NSF's policy-making body, and published in *Science Indicators—1980*. Interestingly, 86 percent of the adults surveyed believe scientific advances are largely responsible for our high standard of living in the United States, and 81 percent think new discoveries will make our lives healthier, easier, and more comfortable. At the same time, however, 85 to 86 percent feel that most citizens are not sufficiently informed to help set goals for scientific research or to choose which technologies to develop. Of eight possible groups to which our society might entrust such decisions, the group most favored by the public is the scientific and engineering community specializing in the question.

I am reassured by this strong public confidence in the worth of scientific endeavor and in the willingness to trust the judgment of science and engineering professionals. But I am also troubled by the great public reluctance to participate in the debate and the decision making. So that is another problem area.

Board work

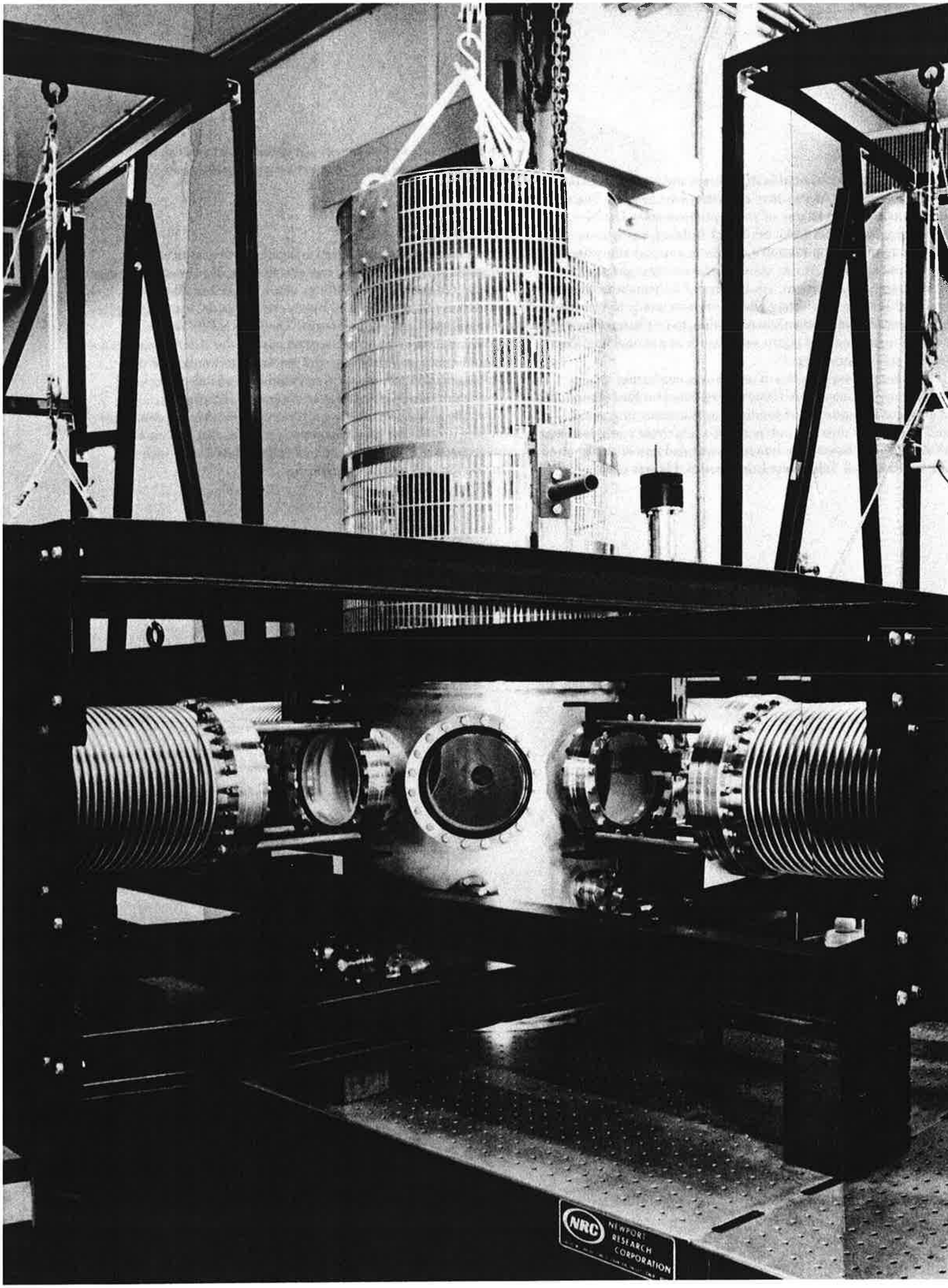
I mentioned the National Science Board and want to add a few words about some of its other activities. Last year the Board turned its attention to one of those problem areas I cited—education. In August 1981 the Board finished a year-long evaluation of the Foundation's efforts to support education in the technical fields. At the same time, it set up a special Commission on Precollege Education in Mathematics, Science, and Technology. That body has three main goals: to identify specific needs and problems in education, to help groups trying to address them, and to suggest ways to focus national attention on this serious problem.

Another noteworthy Board action was conferring its prestigious Vannevar Bush Award. Presented for the second time, this award recognizes outstanding contributions in science and technology through public service. This year's recipient was William Oliver Baker, a polymer chemist and retired chairman of the board of Bell Telephone Laboratories. He was cited for many years of service—in government, university, and industry settings—to advance education and research in the sciences.

Looking ahead

New knowledge gained from grappling with scientific questions is the intellectual raw material for economic progress, for a better quality of life in this country. And investing in research is the best way I know to create, rather than deplete, a natural (and national) resource. True, we at NSF are scrutinizing all of our programs as part of the Administration's economic recovery program. But we are determined that the Foundation will preserve the essential core of its support for university research in the sciences and engineering.

Despite all that we face, the future of our knowledge enterprise remains bright. We may encounter setbacks, but we hope that enterprise will eventually gain a broader base of support. Our nation will be stronger for it.


NRC
NEWPORT
RESEARCH
CORPORATION

Mathematical and Physical Sciences

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Research in the mathematical and physical sciences pursues the understanding of fundamental physical laws. It provides the conceptual base for future technological, economic, and social growth. To further this effort, NSF's programs in mathematical and physical sciences support mathematics, computer science, physics, chemistry, and materials research that does the following:

- Creates new mathematical knowledge and applies it to a better comprehension of physical and social phenomena.
- Develops an understanding of the science that underlies computer technology and formulates design principles for computer hardware and software systems.
- Advances knowledge of the physical laws governing matter and energy and the interaction between them.
- Stimulates the progress of modern chemistry in such fields as chemical synthesis, analysis, dynamics, and structure.
- Promotes understanding of the phenomena and principles that govern the properties of materials.

A key Foundation goal is to ensure that the most highly qualified investigators in each discipline have the resources, including necessary instrumentation, to carry out their research. To provide these resources, NSF offers different kinds of support, ranging from individual research projects through departmental laboratories at universities to national user facilities. The support mode depends on the specific needs of each discipline and the requirements of the research proposed.

Most awards assist individuals or small groups of faculty members who, with graduate students and postdoctoral associates, carry out research projects in their own laboratories.

The increasing cost of modern, sophisticated research equipment and facilities means that scientists must share their use more frequently. Therefore, NSF supports 13 interdisciplinary materials research laboratories, several nuclear physics research laboratories, and 5 coordinated experimental research facilities in computer science.

The Foundation also supports several 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 the Massachusetts Institute of Technology; and the Small-Angle Scattering Facility at Oak Ridge National Laboratory. At these sites, university-based scientists use equipment and facilities that would otherwise be unavailable.

NSF is also exploring alternative modes of support in some disciplines. Among them are a theoretical physics institute and two mathematical sciences research institutes.

With the evolution of powerful new theoretical concepts, incisive experimental approaches, and sophisticated modern instruments of unprecedented power, resolution, and sensitivity, the physical and mathematical disciplines continue in a period of exceptional activity and opportunity. Examples of recent accomplishments include the following:

- Mathematical models to explain the division of living cells. In this research, new types of computers simulate folding motions observed in developing embryos.
- New understanding of the inherent difficulty of solving computational problems. This is one of several areas affected by advances in very large scale integrated circuitry, an integral part of the recent major research activity in computer science.

Table 1
Mathematical and Physical Sciences
Fiscal Year 1979, 1980, and 1981

(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Mathematical Science	885	$ 22.78	911	$ 24.90	972	$ 28.27
Computer Science	263	16.77	265	18.40	266	22.33
Physics	379	61.66	408	63.21	427	72.09
Chemistry	905	45.23	886	51.30	875	57.62
Materials Research	710	62.42	747	68.52	766	76.17
Total	**3,142**	**$208.86**	**3,217**	**$226.33**	**3,306**	**$256.48**

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

- The discovery of several excited states of a new particle of matter, thought to contain the fifth quark. This finding is being studied with the Cornell Electron Storage Ring, an electron-positron, colliding beam accelerator designed to achieve energies of up to 8 GeV, or billion electron volts, in each beam.
- New insights into the action of receptor sites on the surfaces of living cells, aided by a novel technique using gamma-ray spectrophotometry. This is one of many new opportunities for discovery in chemistry that can be traced directly to advances in instrumentation.
- The use of small-angle neutron scattering to study voids in metals caused by stress. This illustrates instrumentation-dependent research in the multidisciplinary field of materials research.

The high level of scientific activity in the mathematical and physical sciences holds great promise for achieving a better understanding of our world. It may also be the scientific basis for future national economic growth and productivity. One has only to consider the richness of modern mathematics, the challenge of complexity in computer science, and our progress in understanding the fundamental forces and constituents of physical matter to appreciate the intellectual content of these disciplines. At the same time, the widespread applications of lasers, discoveries in modern synthetic chemistry, and the unique properties of new materials show potential for serving the future needs of society.

Mathematical Sciences

Two major activities make up the mathematical sciences program at the Foundation: core mathematics and applied mathematics and statistics. Core mathematics does not deal directly with objects and events of the physical world. Rather, it focuses on mathematical objects created in the human mind and communicated by graphic symbolism.

Applied mathematics is a more ambiguous term. Some use it to refer to mathematics created with the goal of understanding the world around us. A second usage is to call mathematics applied whenever it is used to further understanding of observed phenomena. Thus the term "applied mathematical sciences" has come to be used to refer roughly to areas of scientific knowledge heavily saturated with mathematical structures. Examples are classical mathematical physics, operations research, certain elements of computer sciences, mathematical economics, and mathematical biology.

Statistics, as well as the probability theory that underlies it, is obviously a kind of applied mathematics, but it is such a distinct field that it is almost always described separately. Statistics is concerned with collecting and processing data and with developing methods to draw inferences from limited data.

In terms of dollar obligations, core mathematics represents about 75 percent of the Foundation's mathematical sciences program and applied mathematics and statistics about 25 percent. Administrative and definitional differences make it difficult to get accurate estimates of total Foundation support compared to that of other agencies; however, available data indicate that NSF provides about 65 percent of the total federal support for the mathematical sciences and more than 95 percent of the support for 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, than at any time in our history. Major trends in the past few decades are the growing synthesis of the discipline's subparts and the use of computers in mathematical research.

For example, representation theory is being used as both a tool and an object for study in questions related to mathematical physics, group theory, combinatorics, automorphic forms, number theory, and classical analysis. It seems to provide a unique way to investigate related algebraic and analytic structures.

Similarly, work in operator algebras, operator K-theory, ergodic theory, harmonic analysis, and Lie algebras is also contributing to renewed interest in mathematical physics. Finally, computers are serving as tools to test conjectures and suggest additional mathematical problems.

This section describes some of the areas in which major activity is under way along each of these mathematical "tracks."

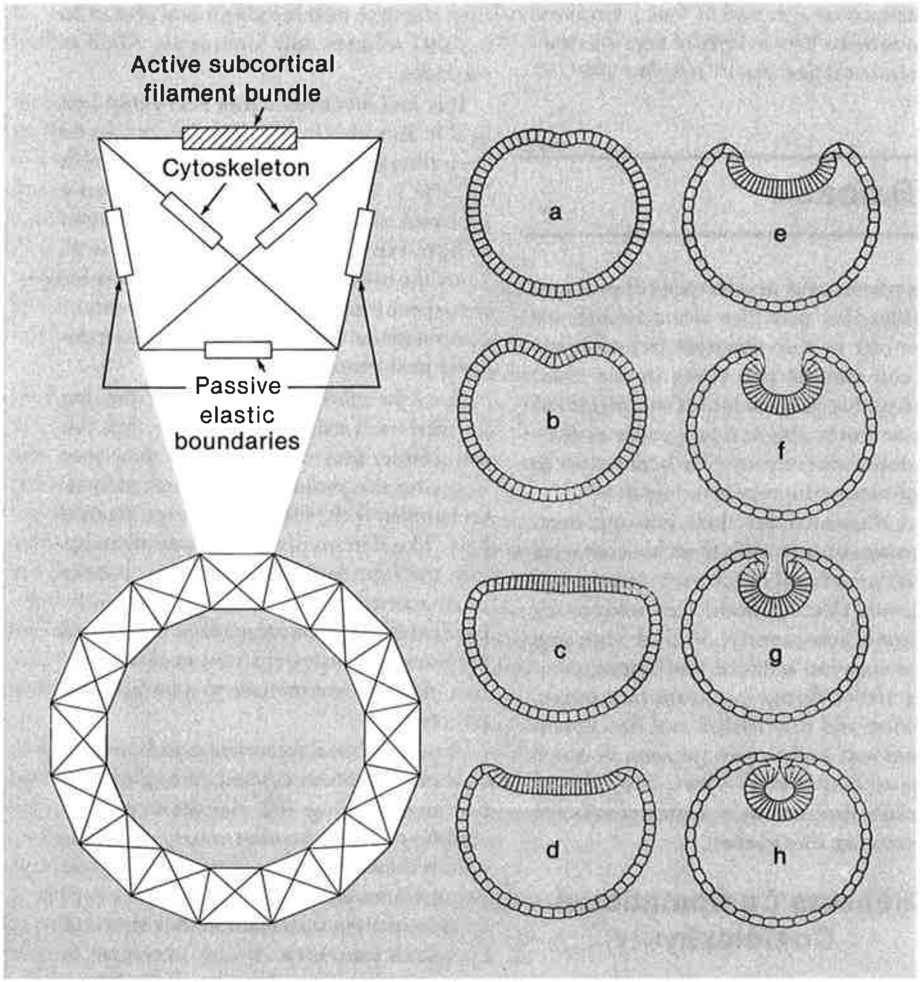
Invagination and Folding in Sheets of Epithelial Cells

It has long been known that movements of populations of biological cells are accompanied by local changes in the shape of individual cells. Several researchers have tried to correlate observed cell-shape changes to the morphogenetic process in which the changes are involved. The work of Garrett Odell of the Rensselaer Polytechnic Institute and George Oster of the University of California, Berkeley, is supported jointly by the applied mathematics and cell biology programs at the National Science Foundation. These two scientists feel that the shape changes must result from coordinated forces generated by the cells. The basic questions, then, are how those forces occur and how they are coordinated among the cells to produce the globally coherent folding motions observed in embryonic epithelia.

Electron micrographs of epithelial cells with their outer, or apical, ends sheared off show a bundle of microfilaments arranged as a purse string and circumnavigating each cell's apical end. These filaments are known to be capable of contraction when triggered chemically. The filament bundle in one cell is connected to those in neighboring cells by various protein structures that can be thought of mechanically as strong rivets. The bulk cytoplasm also contains an active, structural meshwork of protein fibers.

For efficiency in calculation, and because no essential features are thereby sacrificed, Odell and Oster have confined their attention to two-dimensional, cross-sectional models of cells. A typical cross-section can be pictured as a trusslike structure in which the cross-members represent the cytoskeleton. The cross, lateral, and bottom members of the truss are assumed to be composed of a passive viscoelastic material, while an active viscoelastic material apparently makes up the top member.

To produce the simulations of the enclosing or ensheathing invagination process, Odell and Oster consider an initial configuration of cells which, in the absence of chemical triggering, would be in equilibrium.



Developing embryo. Each cell in the ring that makes up an early embryo can be treated mathematically as a truss whose parts represent the basic intracellular structural members (see enlargement at top). The ring of truss diagrams represents the early arrangement of cells in an embryo. When the basic physical and chemical interactions of the system are simulated on a computer, the movements of the embryo as it forms a neural tube are accurately predicted (steps a-h at right). This is an example of the wide applications of mathematical and computer sciences—in this case to understanding cell and embryo development.

The question is, can autonomous chemical triggering of successive outer cells in the top half of the structure produce the folding motions seen in the laboratory? The configuration is essentially a ring composed of the trusslike diagrams by which cells are represented.

The equations of motion for the structure are written down by insisting that the sum of all forces and moments at each node of the composite structure is zero. This hypothesis neglects all inertia terms—a valid approximation since the cell motions are slow. To start the system, the scientists increase the simulated chemical concentration in two outer cells at the top of the structure. The system of differential equations produced is then solved numerically and the output at each instant is represented graphically. These simulations resemble faithfully the folding motions seen in the actual cells.

One of the principal points established by this project is that there need be no master plan for a developmental event. Instead, each of many similar participating cells responds to local conditions. It is the collective interaction of these cells, constrained by the physics and chemistry of the situation, that amplifies simple individual responses into a complex and globally coherent motion.

Geometry of Manifolds

Remarkable advances have been made in recent years in deducing the global properties of a surface, or a higher dimensional manifold, from its local properties. A typical question of this kind goes as follows. Take a surface with zero curvature everywhere, such as a plane or a large cylinder. (Zero curvature means, for example, that a bug living on a cylinder too large to circumnavigate would have no way of measuring anything on the surface by which it could distinguish the cylinder from a plane.) Cut the surface up into small pieces and present them to a mathematician in a basket. Let the mathematician examine them individually but not attempt to reassemble them into an entire surface. Under this constraint, what can be deduced about the obtainable surfaces?

The classical solution to this problem, with analogs in higher dimensions, is that only the plane, the cylinder, and something called a flat torus are possible if the surface is to be complete and have two sides, while a Mobius band and a Klein bottle are possible if the surface may be one-sided. Now a vast generalization of this result has been proved by Russian emigré Mikhail Gromov of the State University of New York at Stony Brook and the Institute des Hautes Etudes Scientifiques in France.

Gromov considers the related problem where the pieces are not flat but nearly so. He also insists that the resulting surface or higher dimensional manifold could fit into a specified box when fully assembled. This second condition avoids the uninteresting case of a sphere of large radius, which is nearly flat everywhere.

Gromov's result again specifies the possible manifolds. (As a class, it turns out that they had been previously investigated by geometers for other reasons.) Each of the manifolds can be assigned metrics for measuring distances between points on it. Moreover, Gromov shows that such a metric can be chosen to make the resulting curvature as small as desired everywhere on the manifold, but not in general zero.

Other striking results of this same general character have come from the methods Gromov has invented. He has achieved results dealing with manifolds of everywhere-positive curvature, generalizing the classical result that constant positive curvature produces a sphere. He also has achieved results that deal with everywhere-negative curvature, the sort that produces a saddle or a mountain pass. For his contributions over a period of years, Gromov was awarded a Veblen Prize of the American Mathematical Society in January 1981.

Computer Science

Unlike the mathematical sciences, which have a long and rich tradition, computer science is barely 20 years old. Owing to its rapid development, trends are more easily discerned here than in a more established discipline. Perhaps the most striking change the science has undergone is in its increased concern with the computing process itself, as distinguished from the art of getting answers from the computer.

In this connection, a parallel can be drawn to the role of mathematics in science. Each scientific discipline devises its own mathematical methodology to solve problems. In doing so, it draws from the incredibly varied and centuries-old framework of mathematics. These mathematical constructs often arose from practical needs of the time that spawned them; often they were products of a quest for mathematical elegance and beauty. In any event, the mathematics stimulated by old problems, many of them no longer interesting, is continually revived for the solution of pressing new problems.

Computer science is rapidly assuming the same kind of role. Twenty years ago, a scientist who was adept at using a computer to solve a particular class of problems, and who made this a principal activity, might have been called a computer scientist. Today this is no longer true. Research is revealing structural similarities among some apparently very different problems when they are viewed from the perspective of computing. And it is showing some surprising differences among others. The study of these structures and their significance for computer design, irrespective of the ultimate application, is defining the new field of computer science.

The Foundation's research programs in computer science, growing and changing along with the community of computer scientists, have consistently emphasized basic research and the application of computers to research. This has not been easy; 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 program activities that provides scientific balance in the face of the relentless technological and commercial pressures in the field. Keeping that balance is the first priority of the computer science programs as they contribute directly to NSF's mission: to promote the progress of science.

As for research directions, one clear trend is the surge of activity in those areas affected by recent advances in very large scale integrated (VLSI) circuit technology. Algorithmic complexity, VLSI design and design support, artificial intelligence, computer networking, program languages, graphics, and distributed and concurrent systems and architecture are areas in which major activity is under way. This section describes research achievements selected from among these areas.

Finessing Computational Complexity

A major thrust in theoretical computer science for the past decade is investigation into the inherent difficulty of intractable computational problems. The area is known as computational complexity; its central knot is the P=NP problem.

Problems in the class P have the property that their solutions take computer time that grows as a polynomial of the problem size. For problems in the class NP, the computer time needed just to determine that a possible solution is indeed a solution also grows as a polynomial of the problem size. But the best that can be said of solutions to the NP problems is that they can be found in computer time that grows exponentially with problem size.

To illustrate polynomial growth, if the polynomial is a quadratic one and the time required to solve a problem of size 10 is 3 seconds, then the time to solve a problem of size 20 is 12 seconds and size 40, 48 seconds.

To illustrate exponential growth, if the exponential is 2^n and the time needed to solve a problem of size 10 is 3 seconds, then the time to solve a problem of size 20 is 3,000 seconds and for size 40, 3 billion seconds.

It is known further that every problem in P is also in NP. But it is not known or even thought likely that every problem in NP is in P. This is unfortunate, since many problems of practical importance are known to lie in NP but are not known to be in P. Thus the best computer programs to solve these problems need infeasible amounts of computational resources for only moderate-sized problems.

Since the solution to P=NP (i.e., proving its truth or falsity) has proven thus far intractable, much research has gone into finessing the problem. Two such efforts, undertaken with NSF support, are discussed here. The first involves new investigations into the foundations of computer science in an attempt to show that P=NP is independent of normal mathematics. The second involves redefining the notion of a "solution" from a deterministic to a probabilistic notion.

A mathematical statement is independent of a mathematical system, provided that neither including the statement nor including its negation causes contradictions within the system. The statement that two parallel lines never meet is an example of an independent statement in the context of Euclidean geometry. If the statement is assumed true, then the normal Euclidean geometry is obtained. If the statement is assumed to be false, then geometric systems corresponding to Einstein's space-time universes can result.

Several mathematicians have taken this approach to the P=NP problem. Juris Hartmanis and John Hopcroft of Cornell University were the first to suggest that P=NP may be independent of the normal axioms of mathematics. Richard Lipton of Princeton University and Richard DeMillo of the Georgia Institute of Technology actually produced natural, although weak, mathematical systems that were independent of P=NP. Finally, Paul Young and Deborah Joseph of Purdue University discovered systems approaching the power of normal mathematics in which P=NP is independent. The ultimate result has not yet been obtained, but there have been significant advances in logic and the foundations of computer science.

A second way of getting around the P=NP problem (especially if the answer turns out to be false) is to redefine the notion of a solution. One possible redefinition is not to insist that a solution be the correct one all the time, but instead just a very high percentage of the time. Michael Rabin, of Harvard University, first recognized the importance of such an approach and developed an algorithm to test whether large numbers were primes. This algorithm ran in polynomial time, compared to the exponential time of the best known algorithms. Assuming this algorithm were run 1,000 times a second, it would produce a wrong answer only once every 10^{22} years, considerably longer than the lifetime of the universe.

The algorithm has since found applications in cryptographic systems. Extending these ideas, Yale University's Michael Fischer, along with Michael Rabin, has used probabilistic algorithms to solve important operating-system problems. These results have opened an entirely new area of study that could ultimately have far-reaching effects.

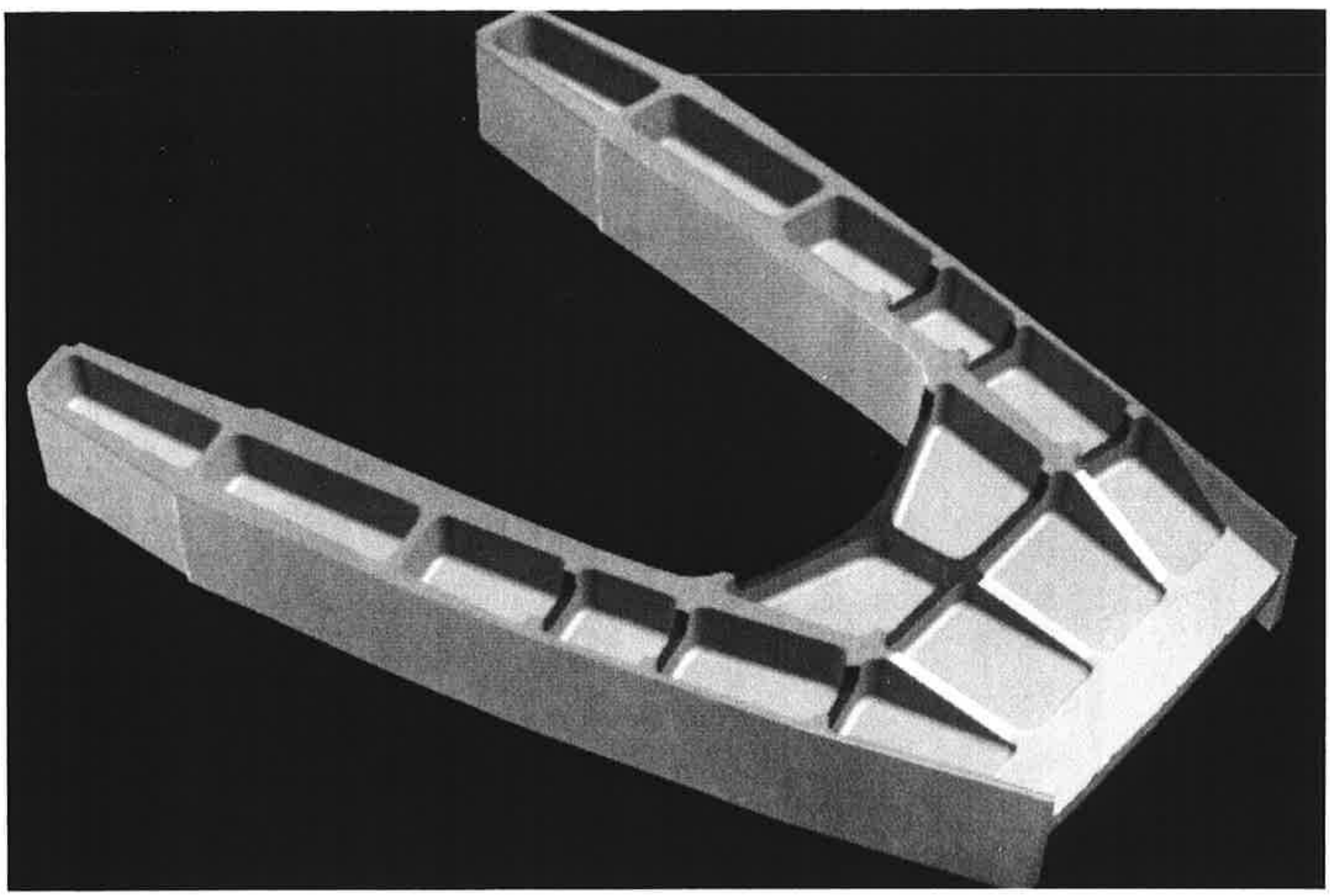
Computer-Aided Sculptured Surfaces

Advances in theory and algorithms have made it possible to develop a system that provides both good computer models for representing free-form, sculptured-surface objects and a high-quality graphics capability for producing accurate images. This capability is necessary to design many common objects such as automobiles, airplanes, and telephone handsets. Since geometric design is largely an interactive visual process, it is paramount that a designer receive very accurate computer displays of the current shape of the object being designed.

Until recently, one of the major problems in the areas of computer-aided geometric design and computer graphics has been that of curve and surface representation. Despite extensive research in these areas, surface-description models used to calculate geometric properties and model representations needed for graphic display had to be considered separately. This made them cumbersome to use.

At the University of Utah and with NSF support, Richard Riesenfeld has collaborated with Elaine Cohen and Tom Lyche to extend a surface-description model and develop a new algorithm. The new construct allows a single model to be used for surface description, graphics display, and the computation of geometric properties. These ideas are embodied in Alpha-1, a system for computer-aided design and modeling of such geometric objects as aircraft bulkheads.

In Alpha-1, the geometric computing capability that produces shaded images also



Bulkhead design. This aircraft bulkhead part, like other free-form and sculptured-surface objects, can now be modeled and displayed in a single, simplified computer-aided design system. Such a system provides the human designer with a better and more efficient way to specify manufacturing steps. (University of Utah photo) supports important geometric processing operations. Among these are the computation of attributes such as volumes, mass properties, and the numerically controlled machining toolpaths used in manufacturing. This capability is needed to move the geometric design into a computer-based manufacturing process.

The integration of these essential processes into a single computer model, as Alpha-1 is meant to accomplish, can result in important economies and more productivity. It can help build mechanical objects that are better in terms of performance, cheaper in terms of required design and manufacturing hours, and more streamlined in the translation from conception to final production.

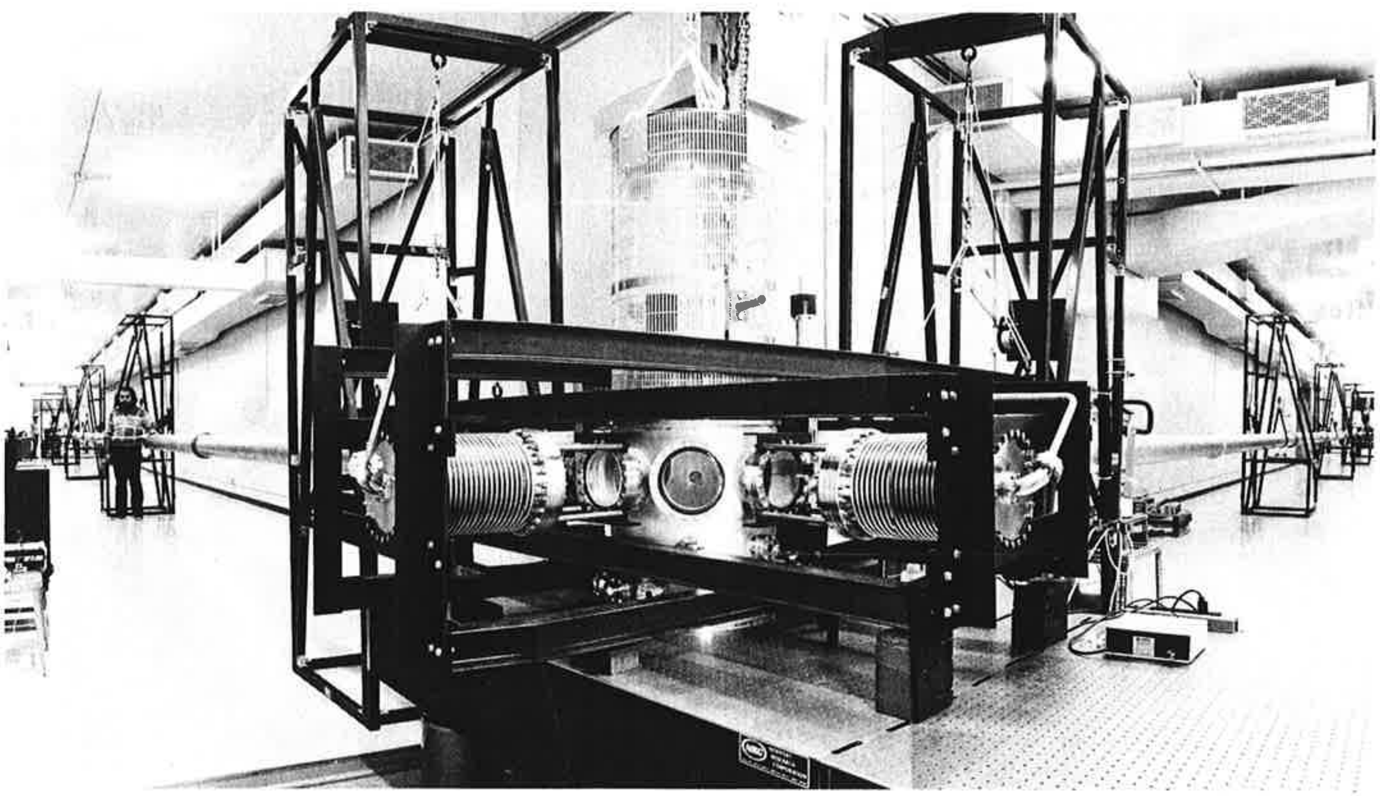
Physics

Physics is the theoretical and experimental study of matter and energy and of the interactions between them. This research emphasizes the underlying principles and symmetries of nature, the aim being to unify our understanding into one self-consistent explanation. Simplicity and elegance are important features of physics theories, while complexity and sophistication characterize the experiments. The National Science Foundation supports theoretical and experimental studies in all major areas of physics research, as described here.

Elementary particle physics involves the most elementary forms of matter, including searches for elementary particles and measurements of their properties and interactions with one another. Elementary particles fall into families: leptons, quarks, and gauge particles. In the last few years, particle physics has experienced an incredible record of success, and the entire community feels the excitement of the recent fundamental discoveries. Evidence for a fourth quark (charm) was found with the discovery of the psi meson in 1974. A fifth quark (beauty) was produced in 1977, and mesons containing beauty are under intensive study. A new lepton (the tau) was found, and indirect evidence for gluons was observed. There is some experimental evidence, inconclusive at this writing, that free quarks have also been observed.

Nuclear science is the study of nuclear structure and dynamics and of the effects of the substructure of neutrons and protons on the characteristics of atomic nuclei. The quark-gluon theory is gaining some acceptance in describing interaction between nucleons at very short distances, while the older, meson-exchange theories still prevail for longer distance. Clustering of particles in nuclei hints that nuclear forces may not be simply a sum of interacting pairs.

Atomic, molecular, and plasma physics



The long arm of physics. This prototype gravity-wave detector at the California Institute of Technology is a laser interferometer with arms 40 meters long. With it, scientists are developing our ability to detect gravitational radiation from astronomical sources. Such studies in gravitational physics can lead to other research advances in cosmology, astronomy, and the behavior of matter under all kinds of conditions.

focuses on the ground states of electrons, protons, and neutrons; the properties of their combinations into simple atoms and molecules (neutral and ionized); and the interaction of such atoms and molecules with one another and with electromagnetic and other fields. Included is the study of the properties of plasmas—dense, ionized gases in which collective, long-range coulomb interactions dominate.

Gravitational physics is the study of the consequences of Newtonian and post-Newtonian theories of gravity, especially general relativity. During the past decade, outstanding experimental groups began to migrate into gravitational research, bringing new and powerful technologies from other fields. One of the most exciting basic research challenges facing physics is the effort to detect gravitational radiation. In the coming decade, present efforts to develop gravity-wave detectors are expected to mature, causing a major transformation of both tools and results in this field.

Theoretical physics gives the framework for interpreting and suggesting experiments in elementary particle, nuclear, atomic, plasma, and gravitational physics. Two of the four fundamental forces of nature, the weak and electromagnetic forces, were recognized as a single force through the use of gauge theories. Attempts to add a third (the strong) force, producing a grand unified theory, have led to the prediction that the pillar of stability of the universe, the proton, is unstable. (Its lifetime would be about 10^{31} years.)

Theorists hope to join the gravitational force to the other three. They are also exploring the possibility that the very high energies where the forces become unified can be probed by looking for astrophysical evidence of the events that occurred just after the Big Bang. At times sufficiently close to the Big Bang, the universe was hot enough for particles to have the tremendous energies required to show the effects of unification.

The interaction between theory and experiment is particularly dynamic in physics at this time. New technologies allow measurement of effects previously inaccessible, giving rise to stringent tests of theories. At the same time, theories suggest the new experiments needed to establish them as models for understanding physical phenomena. Some noteworthy results from the recent past are described in the highlights that follow.

Magnetic-Field Reconnection in Plasma

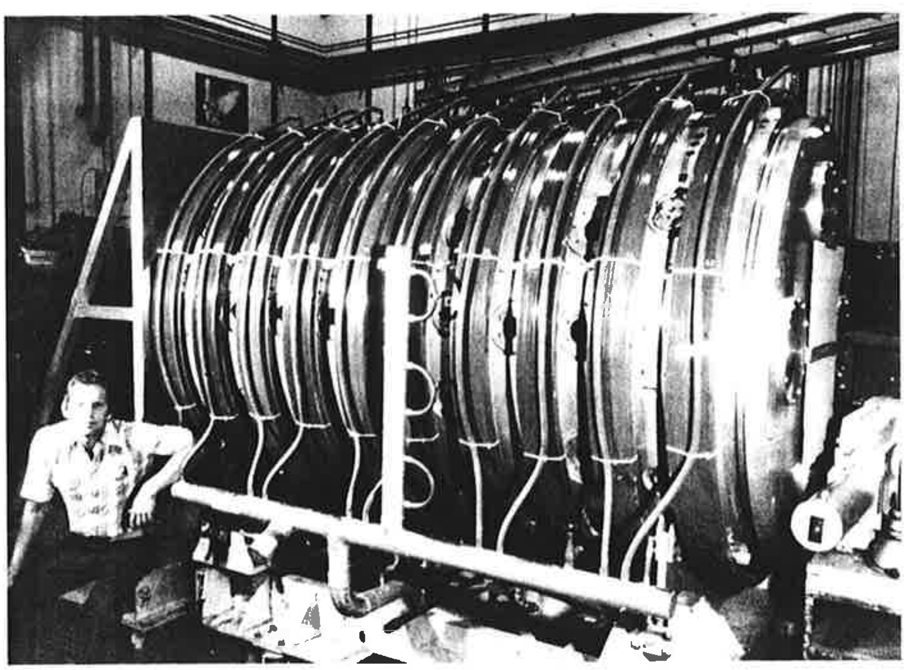
A plasma is a gas of charged atomic fragments—ions and electrons—so hot that they do not recombine to form neutral atoms. Since a plasma consists of charged particles, it is a good conductor of electric currents. Another property that distinguishes it from a cooler gas of neutral particles (such as air at normal temperatures) is that the individual particles, hence the plasma as a whole, respond to electric and magnetic fields.

Matter occurs naturally in the plasma state much more frequently than in cooler neutral or condensed forms. Within our solar system, the sun, the sun's outer layers, and the streams of charged particles impinging on the earth are all plasmas of widely differing densities.

The plasma state is increasingly under investigation in the laboratory, both to model naturally occurring phenomena and to mimic them, as a fusion reactor would. A key question in all this work concerns the interaction of a hot plasma with a magnetic field. Such a field can be generated by currents within the plasma and thus move with the plasma, or it can be externally generated to confine the plasma. In either case the plasma itself interacts with the field and modifies it.

In the extreme case of a perfectly conducting plasma, one that has zero electrical resistivity, magnetic fields behave in a special way: the field lines can be considered as being "frozen" in the plasma and move along with it. An important consequence of such perfect plasma conductivity is that two plasmas from separate sources, each carrying its own magnetic field, can never mix. When two such plasmas and their embedded fields meet, a thin boundary layer is formed between them. No field lines can link across the boundary. However, if the plasma has even a small resistivity, the field lines can "reconnect." In this event, the oppositely directed fields at the interface between the two plasma regions will join, diffusing through the plasma to form a single field pattern.

Reconnection is important for two main reasons. First, it allows a drastic change in the shape of the field, letting two plasma zones intermingle. Second, energy is liberated by the field as the field lines shorten; this energy can appear as local heating and acceleration of the plasma. Both these developments are of prime importance in



Where plasmas meet. UCLA scientists are using this device to study plasmas, gases of charged atomic fragments that are good conductors of electric currents. The coils shown here generate magnetic fields that deform, shape, and heat the plasma within. This work on the interaction of plasmas and magnetic fields is important to understanding sun-earth relationships and fusion-energy principles.

understanding such phenomena as the effect of the sun on the earth's magnetosphere and the instabilities that can limit plasma containment in fusion devices such as tokamaks.

A new experiment at the University of California, Los Angeles, carried out by a group headed by Reiner Stenzel, has made definitive measurements of the phenomena of recombination under controlled reproducible conditions in the laboratory. Onto a dense plasma one meter in diameter are applied opposing magnetic fields. As expected, a current sheet is found to form in the middle, at the meeting plane of the fields. Local instabilities in the plasma can be measured and shown to lead to enhanced resistivity; the resultant field penetration can be demonstrated and shown to lead to further local plasma heating. Indeed, up to 80 percent of the field energy goes to heat the plasma.

For the first time, a comprehensive picture of magnetic-field-line reconnection in a plasma is beginning to emerge. Many key features of both space and fusion plasmas can be duplicated and studied at a small fraction of the cost and time required for a full-scale experiment.

Beauty Physics

For the second year in a row, the most exciting results in high-energy physics in the United States have come from the Cornell Electron Storage Ring. CESR is an electron-positron, colliding beam accelerator that began operating in October 1979 and is capable of achieving energies of up to 8 billion electron volts (GeV) in each beam.

The meson and baryon families of elementary particles are thought to be composed of more fundamental entities called quarks. The common quarks-*u*p, *d*own, and strange—were joined in 1974 by a fourth called charm, which had been hidden in a new particle called the psi. The charm was hidden because the psi contains both the charm quark and its antiparticle, which has anticharm and which cancels the charm for the psi as a whole. Later extensive investigations verified this interpretation. Recently the upsilon particle was discovered. Three times as massive as the psi, it is thought to contain a new, fifth quark called *b*eauty.

In the first year of operation, the Cornell accelerator was able to verify the existence of the upsilon and to establish three excited states of that particle. In two of those states, a situation parallel to that of psi and the charm/anticharm particle pair is found. Beauty is cancelled by the antibeauty also contained in the upsilon.

The third and highest state of upsilon is especially unstable. In it, enough energy is present so that on decay beauty and antibeauty particles go off in different directions; the bare-beauty particles contain a beauty quark but no antibeauty quark, supporting the beauty-quark interpretation of the upsilon.

In the past year the Cornell accelerator staff has been investigating the properties of bare-beauty mesons, producing important results on their decay modes. Measurements of the average number of charged particles, muons, and electrons have been made. In addition, CESR has verified the decay scheme whereby the quark type changes sequentially from beauty to charm to strange, via the weak interaction, as the bare-beauty particle decays. This work represents exploration into beauty physics, a new subfield of high-energy physics.

Deformed Nuclei

The rare earth elements and the elements with nuclei heavier than lead are interesting because of their unusual chemistries and because their nuclei have deformed shapes. Some nuclei look like footballs and some are oblately deformed or squashed spheres. These strange shapes show the delicate balance between the disruptive electrical energy stored in the nucleus and the nuclear binding energy holding the system together.

For many years these shapes, and excitations of them, have revealed themselves to physicists through the emission of regular gamma-ray patterns. The subtle intensity variations of those patterns gave clues to the intrinsic neutron and proton motions in the nuclei. Now, with newly available high-energy and heavy-ion projectiles, physicists have learned to triple the rotational energy they can deposit in the nuclei. With this much rotation, strange and sudden transitions occur in the nuclear shapes. Particles coupled to each other suddenly become decoupled, altering intrinsic structures.

This fascinating behavior, rich with clues to the strengths of the "long-range" parts of nuclear forces, cannot be studied with conventional gamma-ray line spectroscopy. The gamma-ray spectra at such high angular momenta are ordinarily too complex, too overlapping to be separated into individual lines. Jurg Saladin of the University of Pittsburgh, C. Baktash of Brookhaven National Laboratory, and I. Y. Lee of Oak Ridge National Laboratory have overcome this problem by operating two gamma-ray detectors in coincidence for energy correlation between the two.

A plot of the energy-energy correlation as energy of one detector vs. energy of the other yields a dense sea of plotted points, since each gamma ray is in coincidence with many others. But one sharp gap occurs in such a plot, along its diagonal. A gamma ray cannot be in coincidence with itself, and in a rotational nucleus coincident gamma-ray pairs must have well-defined energy differences; hence the diagonal gap is produced. Any "breaching" or crossing of this gap indicates nuclear energies at which abrupt structure changes occur in the rotator, and sudden transitions in nuclear character. The width of the unbridged part of the gap, on the other hand, is a direct clue to the collectivity or shape of the nucleus at particular excitation energies.

An energy-energy correlation plot for tungsten, for example, shows a reasonably clean diagonal gap with two bridges or "breaks" in structure. One, already suspected, occurs at 600,000 electron volts, or keV. But a surprise was a previously unsuspected second transition near 750 keV. It appears that not one but several abrupt changes in nuclear character occur when the energy deposited in this nucleus approaches a million electron volts. The energy-energy correlation method provides pictures with very simple interpretations that give direct insights into dramatic effects occurring inside nuclei previously regarded just as rotators.

A university group that includes Saladin, Baktash, and Lee, as well as physicists from Michigan, Michigan State, Notre Dame, and Purdue, is planning an ambitious further instrumentation improvement. Instead of only two detectors, they will have six, each surrounded by its own shield. A recent technical development, the high-density crystal scintillator bismuth germinate, makes such multidetector arrays possible in a compact design. This detector system will be developed and later deployed at the new heavy-ion accelerator of the National Superconducting Cyclotron Laboratory of Michigan State University.

Studies of nuclei. At Michigan State University's Superconducting Cyclotron Laboratory, workers install the bottom cap of a cyclotron magnet. The copper piping on the cap feeds current and water to coils elsewhere in the magnet. This accelerator for heavy ions is an important tool in nuclear physics research and experimentation.

Chemistry

Advances in chemistry are vital factors in U.S. science and technology; they rapidly translate into products and services that support the nation's economy. Chemistry provides for human needs through food, medicine, clothing, defense, energy, and a host of chemicals used in our daily lives. Chemistry alone accounts for 6 percent of the gross national product. It also plays a supporting role in food production and a critical role in energy technology, areas that account for more than 30 percent of the gross national product.

NSF's research programs in chemistry provide resources for more than 800 separate research groups across the United States, involving more than 1,000 graduate students and 600 research associates. Instruments purchased through the Foundation's departmental instruments program are available to an even larger part of the research community, particularly young scientists embarking on research careers and the many students supported only by their institutions.

A critical feature of modern chemistry is the need for access to instruments that enable new measurements and allow unambiguous interpretation of chemical phenomena. In this regard, chemistry is fortunate in being able to draw on advances in allied disciplines, such as physics, biology, and electronics. These areas in turn prosper from the creation of new chemical concepts and products.

Instrumentation extends the mind and hands of the chemist, allowing novel ideas to come to experimental reality. It offers a look at the most subtle of atomic and molecular interactions; these are often the basis for understanding the function of molecules in activities ranging from life processes to new technology. Through modern instrumentation, the chemist is less limited by time and the availability of human resources in conducting experiments and making computations. Indeed, none of the chemical research highlighted here would have been possible without sophisticated instrumentation, much of it purchased with assistance from the National Science Foundation.

Along with instrumentation, another feature of modern chemistry is diversity. Research across a broad front is a prerequisite for the discipline as a whole to advance. Nevertheless, work in the various subfields of chemistry is highly interactive and interrelated. For example, chemical synthesis, the tailor making of molecules, lies at the heart of chemistry, and the capabilities of synthetic chemists have improved dramatically during the past decade. The new arsenal of synthetic strategies that has emerged is a direct result of intense interaction between theory and synthetic, structural, and analytical chemistry.

Some results: synthesis of commercial quantities of important biological regulators, new molecules for treating disease, and substances for incorporation in new materials—all provided through chemistry and described here.

New compounds. At the University of Colorado, chemist Mary Rakowski DuBois and her research team have developed unique catalysts that can be dissolved in solvents and continue to function. These molybdenum/sulfur compounds are promising for both commercial and research applications.

Soluble Catalysts

Huge industries producing key chemicals are based on the ability of the surfaces of specially prepared chemicals to accelerate chemical reactions and make them very specific. For example, many of the catalysts used in industrial processes are solids having large surface areas. Reacting molecules are brought together on the surface of the catalyst to interact along relatively low-energy pathways.

One such solid catalyst is composed of layers of metal ions surrounded by sulfur atoms in various arrays. These metal sulfide surfaces are used as catalysts for reactions that remove sulfur impurities from petroleum products. The process is important: if the petroleum products are not desulfurized, harmful pollutants are released into the atmosphere when petroleum is burned. Desulfurization is usually accomplished by the catalytic reaction of hydrogen with the contaminating sulfur, converting it to hydrogen sulfide, a gas that is readily separated.

Chemists want to understand the details of the molecular interaction occurring on the surface of such solid catalysts. However, many of the most powerful techniques for characterizing molecular interactions require that the compounds themselves be dissolved in a solvent. Thus, since the metal sulfide catalysts are insoluble, relatively little is known about their surface chemistry.

Recently, however, chemists at the University of Colorado have prepared new compounds containing molybdenum metal atoms linked to sulfur atoms; these compounds can be dissolved in a number of solvents. Moreover, they are similar to commonly used desulfurization catalysts. Mary Rakowski DuBois, the principal investigator for this group, reports that these soluble compounds show some of the same reactivity as the solid catalysts. For example, sulfur can be reacted with hydrogen to form hydrogen sulfide, using the soluble catalysts. DuBois's research team is now studying these systems to determine how the reactions occur. This information should provide insights into how commercial catalysts can function more efficiently.

Another feature of these soluble catalysts, which makes them of practical interest, is the discovery by DuBois that many of the catalyzed reactions occur at lower temperatures and pressures than required for surface-catalyzed systems. For example, the soluble molybdenum-sulfur compounds can convert hydrogen and sulfur into hydrogen sulfide at one or two atmospheres of hydrogen pressure and 25 degrees centigrade. In contrast, a patented solid catalyst is said to require eight atmospheres of pressure and 250 degrees centigrade. A detailed study of what chemical features are essential in these soluble systems may lead to energy-saving changes in this important commercial process.

Phospholipid Vesicle Systems

Many compounds valuable in cancer and other chemotherapies are toxic to normal cells. Thus the ability to deliver and then release drugs at specified sites in the human body could tremendously improve the utility of the medication. The work of John Baldeschwieler, of the California Institute of Technology, on phospholipid vesicle systems and the influence of their surface chemistry could be the basis for such targeted drug delivery.

Phospholipids are molecules with both organic and ionic components. In water, they form bilayer structures in which the ionic components are in contact with water while the organic components are kept from it. A mixture of phospholipids and water exposed to ultrasonic energy at controlled temperatures produces vesicles—small, shell-like structures of subcellular size. While normal living cells are typically on the order of 1 to 10 microns in diameter (one micron is one millionth of a meter), these synthetic phospholipid vesicles range from 0.03 to 0.1 micron in diameter.

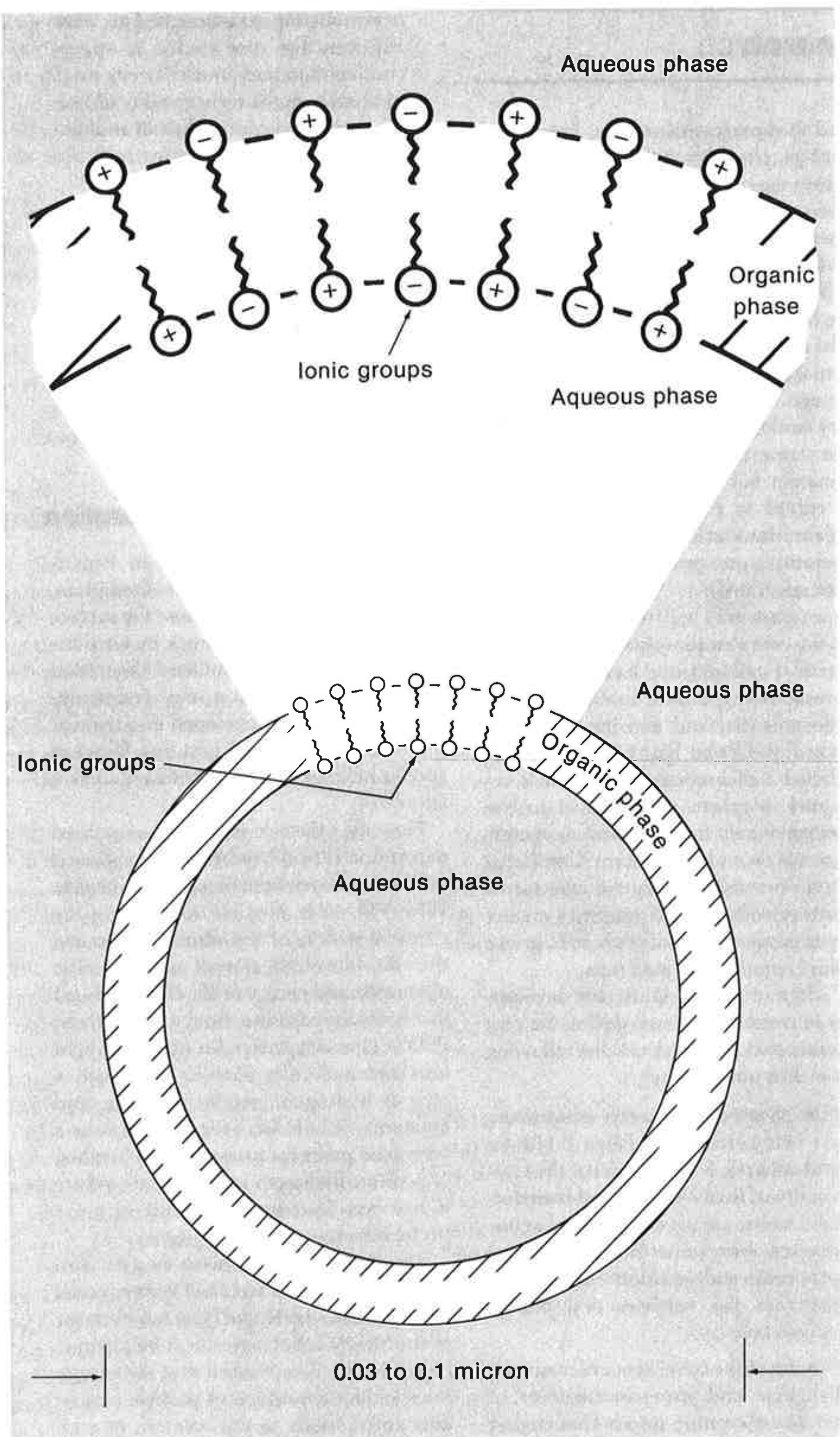
Since a variety of materials can be encapsulated in these vesicles, they can serve as a kind of Trojan horse in a number of applications. For example, they can be injected into living systems to transport drugs from the site of application to target organs in the body.

Using a novel gamma-ray spectroscopic technique, Baldeschwieler and his coworkers have been able to study the structural integrity of phospholipid vesicles in living mice. Based on these observations, they have developed a substantial understanding of (1) how to make vesicles having a variety of desirable properties, (2) how to load material into the vesicles, and (3) how to target phospholipid vesicles to specific organs.

Organopalladium Compounds

Often in the course of following one line of inquiry, scientists will discover an unexpected but even more promising lead. This was the case recently in the chemistry laboratories of George Newkome and his coworkers at Louisiana State University in Baton Rouge.

Newkome was investigating the synthesis and chemistry of a class of compounds consisting of an organic framework with atoms of the metal palladium in the center. Like Colorado's DuBois, Newkome's interest was in learning more about soluble



Microscopic capsule. A hollow vesicle (bottom) that is a hundredth to a tenth the size of a cell can be produced by exposing a mix of water and molecules called phospholipids to ultrasonic energy at controlled temperatures. Such tiny vesicles are a promising means of transporting medication and other substances to target sites within organs. This technique, developed by John Baldeschwieler of Caltech, could lead to major advances in medical research and treatment. (Drawing at top shows enlargement of vesicle part.)

catalysts. He was not looking for new drugs, and his research most definitely was not considered health related. But in the quest for new catalysts it occurred to him that one particular geometric form of his compounds—if he could prepare it—might have therapeutic value similar to that of the widely used cancer antagonist cis-platinum.

Newkome was successful in making the new structure. As a result, he has discovered a class of agents that apparently have antitumor properties and are potentially more active and less toxic than heavy-metal drugs used in experimental cancer chemotherapy.

Newkome and his colleagues have now prepared a whole series of those new organopalladium compounds and have determined the molecular structure for each. In preliminary screening tests with DNA, Newkome's compounds show a greater tendency to destroy rapidly dividing cells than do the platinum-containing drugs in current clinical use. Like most substances used as chemotherapeutic agents, these new compounds exert their disruptive influence during cell division. Since cancerous cells divide more often than their benign counterparts do, they are more susceptible to attack by the drug.

Because these new palladium compounds are about 10,000 times as active toward DNA molecules as the cis-platinum drug, dosages may be substantially reduced, thus reducing the problem of side effects such as kidney damage. In addition, the incredible reactivity of these compounds toward DNA may lead to a new "molecular scissors" for cleaving the DNA double helix at specific sites, permitting the removal of selected sections.

As a bonus, the new organopalladium compounds also act as the homogeneous catalysts Newkome originally set out to develop. For example, in the presence of hydrogen, minuscule quantities of the reagents effectively reduce selected organic molecules. Stable in the presence of heat, light, and oxidizing conditions, these substances may be able to diminish the overall energy needs of some industrial processes. Moreover, minor structural alteration of the parent molecules produces reagents that can deposit a monomolecular layer of palladium metal on relatively inaccessible surfaces. Thus active metal sites can be incorporated directly into reaction vessels to create a different type of catalytic agent.

Materials Research

The emergence of major new and complex materials-related technologies in this century has spurred significant growth and diversification in the basic research patterns of several related scientific disciplines. These activities, loosely termed materials research, have two features in common: close interplay between research in different disciplines and an active interface between basic research and technology.

The increasing sophistication of materials research has led to the need for new types of experimental facilities to extend the limits attainable for experimental probes of basic physical phenomena and to provide new tools to prepare or characterize materials in new regimes. Synchrotron radiation continues to exemplify these developments. During the past year scientists at the Stanford Synchrotron Radiation Laboratory (SSRL), in collaboration with colleagues at the Lawrence Berkeley Laboratory, have moved forward to develop an "undulator" for insertion in the synchrotron radiation source at Stanford.

The undulator will provide a narrower and better focused source that will increase the intensity of ultraviolet and x-ray radiation. The improved source will significantly enhance the experimental capabilities at SSRL for basic research and for applied research such as microlithography. Moreover, the undulator is quite inexpensive compared to the cost of the basic machine and involves no increase in power costs.

Research using synchrotron radiation at SSRL, at the University of Wisconsin's Synchrotron Radiation Center, and at the Cornell High-Energy Synchrotron Source (CHESS) has continued to grow and diversify. New techniques promise to improve greatly our understanding of the microscopic structure and properties of surfaces and interfaces. One of these, photon-stimulated desorption, is described later in this chapter.

The new techniques also have potential use in fabricating or characterizing ultra-small structures. Thus there is increasing interest among university, industry, and government scientists, as well as industry-university collaborative groups, in research related to microelectronics and submicron fabrication.

More use of large facilities to extend the limits of scientific investigations is not limited to experimental science. Theoretical physicists, chemists, and mathematicians are using the computational capabilities of the new generation of computers to solve complex, previously intractable problems. Marvin L. Cohen and his collaborators at the University of California, Berkeley, have given, for the first time, accurate descriptions of phase transitions in solids. Since the formulation of quantum theory about 50 years ago, it has been expected that this theory could give an accurate explanation of the properties of solids. However, this expectation has been slow to materialize with regard to predictions of structural conformations and their changes with temperature, pressure, and the like (i.e., phase transitions).

Apart from very real fundamental problems, the complex computational needs of theoretical calculations have hampered progress. Using a new combination of pseudo-potential and density functional theory, Cohen and his colleagues have developed a theoretical model that is remarkably accurate with regard to the experimental data for solid semiconductors such as silicon and germanium. Compared with previous calculations, the agreements are quite remarkable and portend a greater ability to explain and predict phase diagrams for more complicated materials.

In addition to the significant developments in materials research during the past year, discussed here in detail, the following work is also noteworthy:

- New types of polymeric conductors are being studied by Allen J. Heeger and Allen G. MacDiarmid of the University of Pennsylvania and their collaborators, among others. These conductors have interesting transport properties and significant potential as materials for batteries and photovoltaic cells.
- Studies of the coexistence of magnetic behavior and superconductivity in ternary alloy systems are challenging the notion that magnetism and superconductivity are mutually exclusive. Jeffrey W. Lynn of the University of Maryland and coworkers at the Ames Laboratory and Brookhaven National Laboratory have done important neutron-scattering experiments. This work confirms the coexistence of superconductivity and an oscillatory magnetic state in the ternary alloy of holmium-molybdenum-sulfur in an intermediate temperature range near absolute zero.
- Researchers at the Massachusetts Institute of Technology, led by John Haggerty, Rowland Cannon, and Kent Bowen, are using laser processing of ceramic materials to produce more uniform exotic ceramic powders. This work is expected to improve significantly the fracture properties of ceramics processed from these powders.

Photon-Stimulated Desorption

An ever-present nuisance to experimenters in surface science is ion desorption, in which adsorbed atoms leave the surface of a material after being struck by electrons or photons. Electron-stimulated desorption (ESD), the phenomenon most frequently observed, is being developed as a tool for the study of chemical bonding between specific kinds of adsorbed atoms and surface sites.

Now the existence of photon-stimulated desorption (PSD) has been demonstrated with intense synchrotron radiation beams. With PSD it is possible to measure the chemical identity of the adsorbed atom and the substrate atom, as well as the specific orientation and energy of the chemical bond that holds the adsorbed atom to the surface. PSD is especially useful for observing light ions and molecules such as the positive ions of hydrogen, oxygen, fluorine, and ammonia. It has also been shown to be a very good probe for measuring the bonding of positive hydrogen ions in solids, where it has been extremely difficult to get a probe sensitive to the hydrogen.

The detailed mechanism for the excitation process in both ESD and PSD was proposed by Michael L. Knotek and Peter S. Feibelman of the Sandia Laboratories in Albuquerque, New Mexico. They found that the energy threshold for desorption of positive oxygen ions corresponds to the creation of core holes in metal substrate ions—that is, the creation of vacant inner electron orbitals in the substrate atom.

In order to make the weak flux of desorbed ions observable in PSD, intense beams of synchrotron radiation are necessary. Furthermore, the highly polarized nature of synchrotron radiation, as well as the ability to tune the photon energies with high resolution, has made it possible to be extremely selective about which atoms are excited and which chemical bonds are affected. The PSD yield is sensitive to, and depends upon, the nature of the chemical bonding and varies enormously for different species.

This selectivity has been used by Rolf Jaeger and his colleagues at the Stanford Synchrotron Radiation Laboratory. They have shown that oxygen ions liberated from molybdenum surfaces by PSD exhibit an extended x-ray fine-structure signal. This signal can be used to measure accurately the bond distances between the adsorbed and substrate atoms. Surprisingly, these measurements show the surface atoms to have bond distances identical to those of the bulk atoms.

These experiments indicate that the PSD technique gives a measure of the individual ions adsorbed on surface atoms without appreciable perturbation of the surface. Thus it holds high promise as a sensitive and site-selective chemical-analysis technique at surface layers.

Metal Superlattices

Much recent research has focused on the properties of semiconducting superlattices in which electronic and vibrational structure is determined by a chemical periodicity introduced by crystal fabrication methods. These structures offer the potential of novel materials tailored to preconceived specifications for particular applications. The quantum-well lasers prepared at the Materials Research Laboratory at the University of Illinois are one example.

Similar opportunities with metallic samples, particularly superconductors, have stimulated groups at the Argonne National Laboratory, Bell Laboratories, Northwestern University, and Stanford University to attempt the fabrication of metal superlattices. It has proved very difficult, however, to produce highly perfect, single-crystal superlattices of the type necessary if carrier mean-free paths are to exceed the superlattice period and thus be sensitive to the added periodicity. Consequently it has remained unclear whether high-quality superlattice formation requires the existence of rigid bonds and is therefore confined to covalent materials.

During the past year, a group at the University of Illinois Materials Research Laboratory has succeeded in growing thin-crystal metal lattices via molecular beam epitaxy. These are comparable in quality with the best semiconductor lattices. To make perfectly ordered and uniform crystals a few atoms thick is quite difficult. Molecular beam epitaxy is a method for growing such thin crystals by directing beams of atoms or molecules at a crystal surface and monitoring the growth by very sensitive, computer-controlled diagnostic probes.

This work establishes the important fact that high-quality superlattice structures are not confined to systems with covalent bonding. In the future one can reasonably design superlattices with metallic or even ionic constituents.

The controlled fabrication of microstructures on the scale of atomic dimensions has important scientific and practical ramifications. In the case of a superlattice composed of niobium interspersed with tantalum layers, the constituents of the superlattice are both superconducting at very low temperatures with, however, different transition temperatures for the onset of superconductivity.

For thick layers, the electronic, lattice, and superconducting properties would be simply those obtained as a composite of the two sets of bulk properties. For thin layers, however, size alters the corresponding properties, which are also mixed by effects of the proximity of the two constituents. Thus the ability to fabricate such microstructures offers new experimental capabilities for understanding basic phenomena such as superconductivity. This ability also provides an engineering approach for tailoring materials properties for practical applications.

An Approach to Metallic Oxygen?

Oxygen is typical of many small molecules whose properties have been extensively studied by vapor-phase electronic and vibrational spectroscopy and can be accurately described by first-principles theoretical models. These isolated-molecule studies need to be extended to interactions between molecules; the properties of collections of molecules (e.g., boiling, freezing, structures and properties of crystals, and the transformation from molecular to metallic behavior) can then be compared against theoretical applications.

Oxygen is an especially good candidate for such studies because its ground state and several low-energy excited electronic states are very sensitive to intermolecular perturbation. However, sufficiently accurate experimental studies have been precluded by practical considerations. One of the most severe restrictions: oxygen condenses only at extremely low temperatures or very high pressures and, until recently, properties of vessels that attain such extreme conditions interfered with the measurements. Tests of theoretical models thus could not be made.

An important experimental advance in this area has been reported by Malcolm Nicol of the University of California, Los Angeles, in collaboration with Wilfried Holzapfel in Paderborn, West Germany. They discovered how to confine oxygen in a cell with transparent diamond windows and described several dramatic structural and spectral changes that occur at very high pressures.

In their early studies, Nicol and Holzapfel grew single crystals of oxygen at room temperature and 59,000 atmospheres. They then identified these as crystals of beta-oxygen. (X-ray studies at Los Alamos Scientific Laboratory in New Mexico have confirmed this identification.) This is the first time that it has been possible to grow single crystals of beta-oxygen, thus opening the way to study of its spectra, structure, and unusual magnetic ordering.

Dramatic spectral changes accompany compression of pale blue, fluid oxygen to pink/green beta crystals, orange alpha crystals, and deep red/black epsilon crystals. These spectra are associated with low-energy electronic transitions that are forbidden for isolated oxygen molecules. Thus the spectral intensities and the dichroism of the crystals directly probe interactions between molecules. Nicol and his associates at UCLA are now measuring these spectra under more controlled conditions. They hope to determine the precise dependence of the spectra on intermolecular separation and orientation and compare their findings to results of theoretical computations.

Exploratory studies at even higher pressures are being conducted by Nicol and by Karl Syassen of Universität Düsseldorf (West Germany). Syassen has a unique facility for measuring reflection spectra of strongly adsorbing samples in diamond-window, high-pressure cells. At 390,000 atmospheres, the highest pressure achieved with the available diamond cell, they found yet another dramatic spectral feature. At the blue end of the ultraviolet, the reflectivity of the epsilon oxygen phase approached that of the adjacent steel gasket.

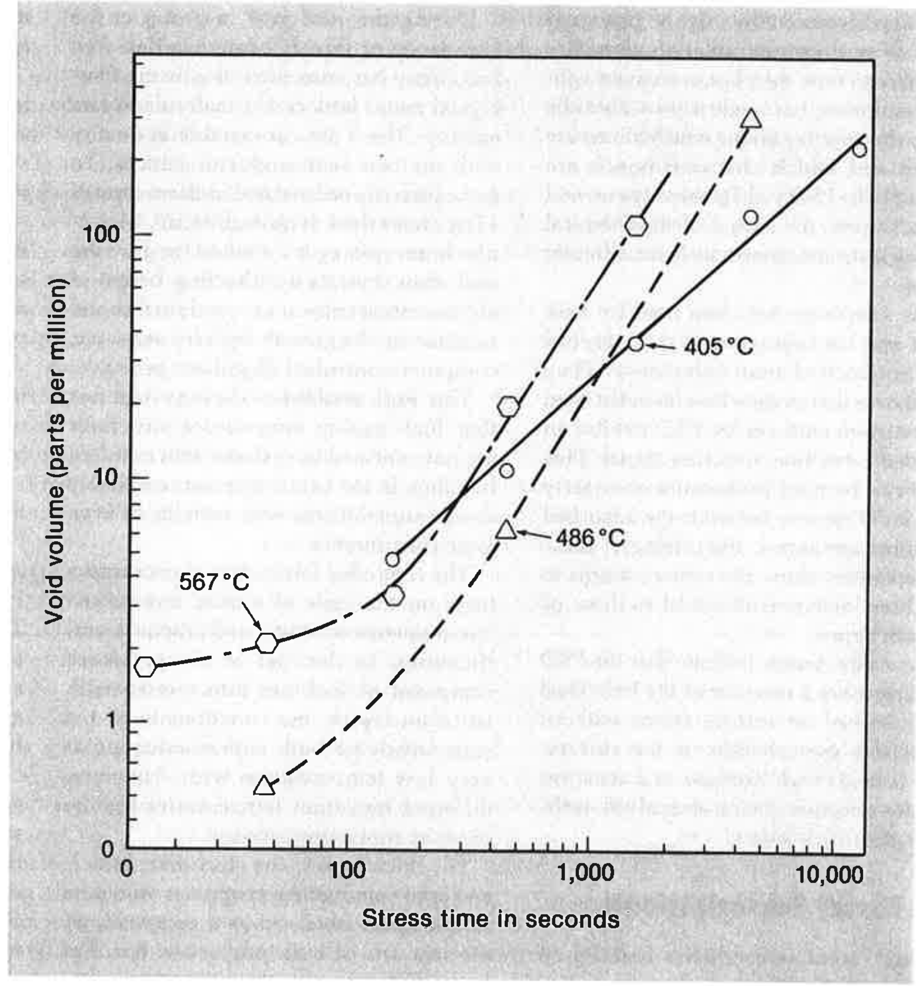
The origin of high reflectivity is uncertain; one likely possibility is that it is a precursor of a transformation to the metallic phase expected at high pressure. That this reflection band appears at the edge of the visible spectrum at 390,000 atmospheres suggests that the metallic transition may be accessible with diamond-anvil cells of a somewhat more complex design.

Grain-Boundary Cavitation of Metallic Materials

Many metallic materials, when subjected to deformation at elevated temperatures, develop small voids on their grain boundaries. Continued stressing causes the voids to grow and ultimately to coalesce, and the material fails intergranularly. Since so many basic mechanisms are involved—for example, vacancy diffusion processes, grain-boundary and matrix dislocation interactions, grain-boundary segregation or migration, environmental effects—this cavitation is of considerable scientific interest. Furthermore, since many structures operating at elevated temperatures, such as reactors and generators, frequently run under conditions that promote cavitation, it is important to understand this phenomenon.

A number of theories explain the growth of grain-boundary cavities, but very few experiments give data on the rates at which voids nucleate and grow. This information, needed to show which mechanisms are responsible for cavitation, is not easy to obtain. The fact that cavitation is a heterogeneous process means that large numbers of submicron-size voids (i.e., voids smaller than one micrometer) must be followed during the course of deformation in order to obtain meaningful statistics on void behavior.

Julia Weertman of Northwestern University has recently begun to use small-angle neutron scattering (SANS) to study grain-boundary cavitation of voids from their earliest stages of development. SANS is ideally suited to sample a large number of voids and to provide statistical information on their number and size distribution.



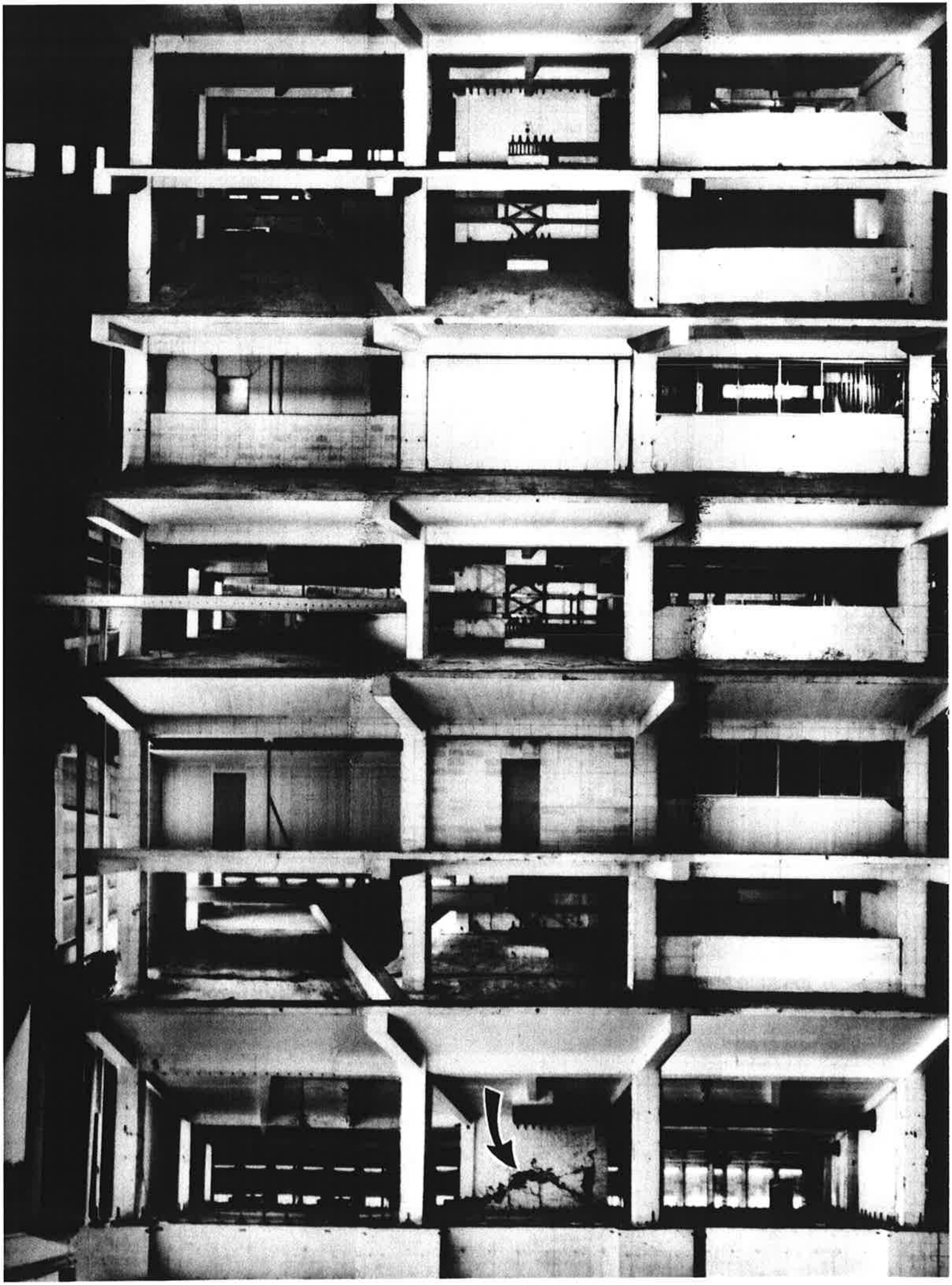
Metal fatigue. A technique called SANS (for small-angle neutron scattering) shows that stress and high temperature can produce, in high-purity copper, structural voids that may cause the material to fail. Voids with volumes measuring less than one part in a million can be measured with SANS, and the formation of cavities can be detected after as little as 15 seconds. The technique will be a key tool in judging the strength of metals.

Weertman believes that this is the first use of SANS to study grain-boundary cavitation, and it is proving very successful.

SANS measurements have shown that, in pure copper fatigued at high temperatures, voids start to form immediately without incubation time, cavitation proceeds even as the boundaries are migrating rapidly, and many voids are left behind in the matrix. The technique is so sensitive that voids can be detected in a sample fatigued for only 15 seconds.

The SANS data have been analyzed to yield information that permits quantitative testing of a recently developed theory of fatigue-induced cavitation. This theory treats the growth of grain-boundary voids in material subjected to fully reversed stress cycling at elevated temperatures. Most cavitation theories assume time-independent loading; they cannot be extended to the case of time-dependent deformation. The growth rate of individual voids has been obtained from the SANS measurements and shown to be highly transient, with a time dependence that agrees very well with the theoretical prediction.

The observed temperature dependence of the growth rate also is in excellent agreement with the theory, as is the finding that the large increase in cavitation with increased cycling frequency is caused entirely by faster nucleation, not by a change in individual growth rates. There are no other data that permit such detailed, quantitative testing of a cavitation theory.



Engineering

2

NSF's programs in engineering support research across the entire range of disciplines. Such research ultimately has an impact on many important national concerns, such as economic growth and competitiveness in world markets, technological innovation and industrial productivity, and national defense.

Few private-sector institutions have either the resources or incentives to perform or support the kind of research that advances knowledge of engineering principles and technology. In recent years, NSF has become a primary source for supporting such research and ensuring the strength of our country's academic engineering base. To emphasize this role in the Foundation and to strengthen NSF's capacity to support engineering research, a new directorate for engineering was established in March 1981. Its programs are grouped in four areas: electrical, computer, and systems engineering; chemical and process engineering; civil and environmental engineering; and mechanical engineering and applied mechanics.

Research topics in electrical, computer, and systems engineering include electronic materials and solid-state devices; very large scale integrated circuits and integrated optics; lasers and optoelectronics; sensors and imaging systems; plasmas and particle beams; computer engineering, machine intelligence, robotics, and automation; information theory and communications; control systems methodologies and networks; and operations research.

Chemical and process engineering focuses on knowledge relevant to the design, optimization, and operation of processes in these industries: chemical, petroleum/petrochemical, food, biochemical/pharmaceutical, mineral, and allied areas. Research includes the development of fundamental principles, design and control strategies, mathematical models, and experimental techniques that cut across a large number of industries and processes. Areas of support include catalysis, combustion, and plasma chemistry; biochemical, electrochemical, macromolecular, and separation processes; particulate characterization and interaction; thermodynamic and transport properties; and renewable and nonrenewable materials processing.

Civil and environmental engineering deals with the basic functions of natural and human-built physical structures and systems from both the elemental and macroscopic viewpoints, and with the interaction between human activities and the natural environment. Areas of research include geotechnical engineering, structural mechanics, water resources, and environmental engineering. Under the Earthquake Hazards Reduction Act, NSF also supports research on the phenomena of earthquake dangers and ways to mitigate these and other natural hazards.

Programs in mechanical engineering and applied mechanics support research that stems from intrinsic interest in phenomena arising in technological applications, as well as the need for solutions to mechanical engineering problems. Applied mechanics deals with the continuum behavior of solids, fluids, multiphase mixtures, and biological materials, including the effects of heat transfer, phase changes, and chemical reaction. Special attention is given to time-dependent or unsteady phenomena. Mechanical engineering research deals with fundamental problems in the behavior and design of mechanical systems and industrial production. It supports research on the

Table 2
Engineering
Fiscal Year 1979, 1980, and 1981

(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Electrical, Computer, and Systems Engineering	340	$ 17.02	349	$ 17.63	465	$ 23.43
Chemical and Process Engineering	277	12.98	316	13.98	367	18.45
Civil and Environmental Engineering	132	8.15	356	9.71	385	28.46
Mechanical Engineering and Applied Mechanics	194	10.71	230	11.27	266	16.01
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**	**$102.94**	**1,483**	**$ 86.35**

* Programs included in these subactivities were transferred to other NSF divisions as a result of the FY 1981 reorganization of the Engineering and Applied Science program.

** Included under Scientific, Technological, and International Affairs in FY 1981

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

analysis and synthesis of machines and mechanical systems and on optimization of manufacturing processes.

NSF also has a problem analysis group to identify and analyze major national problems with significant scientific content. Part of the group's task is to give a preliminary assessment of the appropriate role of science and technology and the federal government (including NSF) in solving those problems.

NSF provides special opportunities for new investigators through its engineering research initiation grants. Full-time engineering faculty members who have had no prior substantial support can receive grants for theoretical and/or experimental research in areas that will expand their capabilities. In fiscal year 1981, 123 such awards, totaling $5.3 million, were made.

NSF also gives awards for specialized research equipment to improve the quality or broaden the scope of research that an institution can perform. This new equipment can be used for many different research projects, and the institution is expected to make a reasonable contribution of its own funds toward the purchase. Fifty-nine equipment awards for $1.8 million were made in fiscal year 1981.

In the past several years many exciting areas of engineering research—among them robotics, microelectronics, bioengineering, arc technology, and plasma chemistry—have opened up. The rapid development in these and other areas has far exceeded NSF's ability to support all the meritorious projects proposed, or even all the most important research. Moreover, new research equipment for universities, essential for adequate training of the next generation of engineers, is prohibitively expensive, and existing equipment is (or is rapidly becoming) obsolete—thanks to the rapid pace of instrumentation innovation and progress.

In light of these substantial pressures, NSF tries to allocate its funds to ensure that the nation's most vital needs are met. Examples of the past year's notable research results are described on the following pages.

Electrical, Computer, and Systems Engineering

Research on devices, methodology, and processes in this field of engineering affects American life, industry, and world position. NSF supports research leading to the design, analysis, and fabrication of systems that display "intelligence" in widely separated or distributed locations. Data are transported over channels built from materials with low-loss properties, and they are processed in computers with architectures never before realized due to limitations on size and complexity. Researchers are continually improving the efficiency of signal sources by using new materials and switching techniques. Underlying much of this research is the continual development of new knowledge needed for the faster, smaller devices and phenomena that are at the heart of more effective and efficient products.

NSF also supports research to generate knowledge required in automated machine processes. Included here are signal and data analysis, feature extraction, and automated decision and control systems. Applications include robotics, advanced automation, and human-machine interactions for improved productivity. Mathematical and computational methods are being developed for the modeling, analysis, optimization, and control of manmade and engineering systems and processes. Also in progress are techniques that enhance the understanding of systems behavior, improve systems operation and performance via control and optimization, and increase systems robustness. Interactive computer-aided design techniques are being investigated for use in the design of complex control systems and other engineering systems and structures.

Basic research in knowledge engineering has made great strides in recent years, expanding research possibilities in application-motivated areas such as knowledge engineering/knowledge-based expert systems in particular domains, natural language interfaces to computer systems (text and voice), and computational aspects of computer vision. The complex nature of high-capacity communication and signal processing systems requires research in optical communications, large-scale computer communication networks, digital signal processing, information theory, and electronic circuit theory. Research in very large scale integrated microelectronic circuits has expanded as a consequence of the possible complexity of VLSI chips. The implementation of algorithms and theory in VLSI hardware and the automated design of digital systems are possible new areas of research.

Research in integrated optics was born out of the need to investigate very high capacity communication systems. After more than a decade of research, we are at the threshold of fabricating monolithic integrated optical circuits, using optical devices or a semiconductor laser with a microwave electronic diode. Other important results such as mode locking of a semiconductor laser and coupling from a laser to a fiber in a single-mode operation are encouraging for integrated optics.

The real promise for the potential of optical communications is high-capacity, single-mode systems; with optical fibers this promise can be fully realized. Communication systems may transmit voice, video, and/or data. Digital transmission is apparently the most efficient way to transmit these diverse types of information over the same network. Such a network must combine the power of computers with communications to deal with the complexity involved. Optical communications using optical fibers and integrated optics will give the requisite wideband capacity.

Fundamental engineering studies of laser, plasma, electromagnetic, and acoustic phenomena emphasize research that can produce advanced devices and better fundamental technology. Grantees are exploring technical frontiers in optics and plasma science; new laser sources and improved versatility; efficiency, or wavelength, capabilities; picosecond optical devices; nonlinear optical processes; and innovative laser applications.

NSF also supports (1) plasma science research that contributes to our general understanding of the "plasma state" or is relevant to the production and control of high-energy charged particles, and (2) investigations of advanced electron and ion beams, novel plasma-confinement devices, wave phenomena in plasmas, and plasma diagnostics. Foundation-supported work in electromagnetics and acoustics includes wave propagation and scattering; source, detector, and transducer development; and nondestructive evaluation techniques.

The quantum electronics area, which includes lasers and electro-optic devices, is growing rapidly. Although many laser systems have been identified, few have shown the efficiency and versatility that would make them attractive for commercial applications. There is a pressing need for efficient, wavelength-tunable sources in many portions of the spectrum. There are now few coherent sources at wavelengths shorter than 150 nanometers, and progress in coherent source and device technology in the vacuum ultraviolet and soft x-ray regions is proceeding slowly. Free-electron lasers show much promise as efficient and tunable sources throughout most of the optical spectrum, but these devices are clearly still in their infancy. Much experimental work is needed in this area, and advances seem to be hindered by the limited availability of appropriate electron-beam sources.

Remote sensing using laser-backscattering techniques has progressed to the point where many practical applications have been shown, and the field has potential for rapid expansion. In the picosecond optical source area, mode locking of semiconductor diode lasers has been demonstrated—yet another step toward picosecond integrated optics that allows generation of 100-femtosecond pulses. These short pulses are probably the fastest of all human-created phenomena.

High-temperature plasma science has been strongly influenced by large-scale fusion energy efforts supported by the Department of Energy. However, those efforts are becoming so strongly focused that research support has decreased for plasma studies that are not strongly oriented to fusion. Expanded support of basic plasma science is needed to ensure the overall well-being of the field.

Advanced processing techniques such as x-ray and ion lithography, dry processing, and laser and beam annealing are increasing in importance as device size and speed requirements become fundamental limits of microcircuit and system performance. The United States must put more emphasis on these techniques if it is to maintain a lead over other countries in VLSI technology. Microstructures research has reduced dimensions of devices so far that research is needed on new concepts that capitalize on the three-dimensional aspects of the devices, as well as on such new topics as ballistic electrons.

Research in computer engineering seeks a more basic understanding of hardware and software principles and issues in the design, analysis, and implementation of computers and computing systems in an engineering environment. Dramatic developments in large-scale and very large scale integration now make it possible to explore potential new computer architectures that were not practical or feasible before. These developments reopen questions of how to partition physical problems so as to make explicit use of parallel processing and distributed processing, and how to devise new classes of algorithms for these new computing structures.

Scientific and technical advances in materials and computers are a sound basis for multidisciplinary solutions to physical problems facing the handicapped. For example, research from bioengineering has measured bandwidth and transient response of the tactile senses. These findings, combined with results from image processing, permit new tactile displays of visual and acoustic information to substitute for lost senses.

Wave and Beam Instabilities

Studies of trapped-particle instabilities are important to long-term development of fusion-energy production, but the instability phenomenon has not been easy to produce in experimental devices. For example, in the Columbia University Linear Machine, a quiescent steady-state source of collisionless plasma is needed to produce trapped-particle instabilities. Amiya K. Sen and Gerald A. Navratil have made considerable efforts there to develop an appropriate "E x B" source (where the electric field is perpendicular to the magnetic field), but without success. The reasons for their failure appeared to be a high noise level at the necessary magnetic-field strength and problems in getting neutral pressure and appropriate size. The machine has now been redesigned to get around these obstacles.

The E x B discharged source has been replaced by an "E · B" source (where the electric field is parallel to the magnetic field) consisting of a screen cathode and a screen anode. This allows operation at a lower gas-fill pressure and a larger plasma size, provides a uniform plasma without cathode hot spots, and achieves a lower noise level. With these and other modifications, the machine has achieved the operating conditions needed for the excitation of a trapped-ion mode. Moreover, this experiment has shown a previously intractable instability of great importance for toroidal fusion machines.

The Columbia researchers are also studying the nonlinear saturation of any drift wave-type instability in a sheared magnetic field. This has particular application to tokamaks (toroidal reactors with applications in fusion energy). The Columbia team has been able to couple fundamental modes to produce stable, higher-order modes, thus providing a saturation mechanism. They will next try to apply results of this experiment to trapped-electron and trapped-ion modes.

Other work, on control sources, has shown that only 7 to 21 kilowatts of control power are needed to suppress many modes of the trapped-electron instability in a tokamak reactor. Therefore, this is seen as a promising scheme for suppressing trapped-particle instabilities in toroidal fusion machines.

Modern Large-Scale Networks

Large-scale networks of all kinds are pervasive in a technological society, with examples in transportation, commodity flow, service-delivery systems, communications, and computer science. Efficient scheduling and routing in complex networks require sophisticated analytical and computational techniques to conserve resources while maintaining services. Techniques used to solve large-scale network problems include queueing, scheduling discrete optimization, and mathematical programing; they cover stochastic control and optimization, information theory, and computer science. Both exact computer algorithms and approximate efficient heuristics are used to deal with such problems.

Our society continually requires more sophisticated communication networks to store, share, merge, and transmit information between people and machine and between machine and machine. The demand for greater information flow and transfer has created, in the past decade, a great rise in ad hoc, specialized methods that provide immediate solutions but do not deal with longer-term requirements. Today's challenges demand additional fundamental studies of basic concepts in communications, electronics, computers, and control systems.

Fortunately, advances in electronics are making possible new directions in circuit and system design. Novel methods to fabricate integrated electronic components on chips are bringing us rapidly to the very large scale integrated (VLSI) microelectronic circuit era. Within the next few years, we expect to see a million components placed on a single chip. With this kind of "chip power," there is great optimism that the requirements of reliable communication networks will be met through research on conceptual and fundamental issues.

In research on large-scale networks, James Meditch at the University of Washington is focusing on the issues of stability, control, and high performance of networks in which (1) there is competition for resources by many users, (2) control of the network is distributed, and (3) information about the state of the network is generally distributed, delayed, and incomplete. Physical systems of interest include satellite and ground-radio communication networks, automated industrial processes, distributed control stations, and multiuser interactive computing systems. Meditch's research is designed to provide a basic understanding of the conditions for stability, control, and optimization of practical large-scale networks, together with realizable control algorithms to achieve high performance.

One key result in this work came from devising a centralized, "minimum-hop" routing algorithm, which minimizes the number of transmission links (hops) that information traverses in moving from source to destination. This algorithm was the basis for later studies in both centralized and distributed routing algorithms. It is designed to avoid congestion at nodes due to features found in real-world networks, such as finite-capacity communication lines, finite-capacity buffers, and noise. The algorithm needs information only from adjacent nodes to carry out routing calculations.

Continued research on minimum-hop routing has been central in motivating further study of the basic issues of network performance modeling. Using extended rate-distortion concepts from information theory, new and more complete models at both the link and network levels have been obtained. These models capture the effects of channel distortion, model processing, and protocols; they also permit the characterization of network capacity and message delay. Aided by fundamental research and new technology, integrated digital networks of the future will send and deliver voice, data, and picture information mixed for enhanced transmission efficiency and then separated upon delivery.

Chemical and Process Engineering

These Foundation programs are unique in the federal establishment. No other agency has a similar, discipline-oriented support program to produce the general engineering knowledge needed for chemical process design. Ninety-four percent of federal funds for basic chemical engineering research in universities come from NSF. These programs strongly affect the state of the art of the chemical and process industries—a dominant force in our economy, with 55,000 different chemicals (500 new ones each year) appearing in an even larger variety of products and commodities.

Program objectives are as follows:

- To increase fundamental knowledge of chemical process principles.
- To develop and improve mathematical models and design and control methodologies for important classes of chemical and allied processes.
- To devise new techniques for acquiring experimental data and predicting the chemical and physical properties of substances that interest chemical process designers and engineers.

With the national goal of increased energy and material independence, these engineers have unusual research opportunities in renewable resources development, energy-efficient industrial separations, plasma chemical processing, biochemical technology, photocatalysis and catalytic reaction engineering, strategic mineral recovery processes, multiphase fluid transport, and fluidized-bed reactor technology. Emerging areas of importance include biochemical engineering that builds on recombinant DNA science, new biochemical methods to devise useful chemicals from biomass, new semiconductor catalysis using light or electrical potential to direct or control chemical reactions, and plasma techniques for altering metal surfaces.

Chemical and process engineering projects continue to be an important part of NSF's industry-university cooperative research program. The benefits derived from this cooperation are many and include pooling of resources, sharing of ideas, interdisciplinary synergism, clearer identification of problems and enhanced ability to tackle them, and rejuvenation of industrial personnel.

In addition, this NSF program is a catalyst in increasing industry support of universities. For example, cooperation between the University of Minnesota and the Union Carbide Corporation on polyurethane reaction injection molding has resulted in Union Carbide's contributing two additional fellowships to the university. At the University of Delaware's Center for Catalytic Science and Technology, the number of industrial sponsors has increased from 12 to 23 as a result of NSF involvement.

Producing Chemicals and Electricity Together

Fuel cells are a well-known means of directly converting chemical energy to electric energy, but they are not economical except in exotic uses. The economics of the fuel cell would be better if the chemicals produced—in the conventional cell, water vapor and carbon dioxide—were more valuable than the reactants fed in. Now a research team headed by Costas Vayenas at the Massachusetts Institute of Technology has designed a fuel cell whose products are more valuable than the input. Extensions of this research may enable manufacturers of an important industrial chemical to obtain electricity as a by-product. The chemical, nitric oxide, is easily converted to nitric acid, and the United States produces more than 8 million tons of nitric acid per year for fertilizers, explosives, and dyes.

The fuel cell consists of platinum electrodes deposited on the inside and outside surfaces of the wall of a zirconia tube. The outside platinum electrode (the cathode) is exposed to air, and the inside one (the anode) to a stream of ammonia diluted with helium flowing continuously through the tube. At the cathode, oxygen in the air picks up electrons, forming oxygen ions. Attracted toward the ammonia inside the tube, the oxygen ions diffuse through the zirconia electrolyte that forms the tube walls. At the inside of the wall, the platinum anode acts as a catalyst, causing the oxygen ions and ammonia to react, forming nitric oxide and water. Electrons given off during the reaction travel up the anode, through an electrical circuit, back to the cathode, and the process continues.

Using a commercial-scale version of the new MIT fuel cell, a chemical plant producing 300 tons of nitric acid per day from ammonia could also become a 4.8-megawatt power plant, capable of serving a town of 10,000 people.

Multilayer Plastic Films

The rising cost of raw materials and energy forces industries to make better use of their current materials, seek new materials with better economics, and innovate in the usage of all materials, new or old.

For example, in the packaging and container business, thermoplastics have been replacing glass and metal because of the lower overall cost for equivalent or superior performance. Lightweight thermoplastics, formed and joined at low temperatures and with low mechanical forces, require less energy to manufacture and transport than the materials they replace. But they have some limitations as packaging substitutes. For instance, high-density polyethylene is useful in food packaging because it is strong, easy to make, relatively cheap, and a barrier to water. However, its permeability to aromatics and oils bars it from many other potential applications.

Coextrusion of multilayer plastic fibers is one solution, but this move to multicomponent plastic constructions is not without its own problems. Dissimilar materials seem inevitably to possess different rheological properties (and often "in the wrong direction"). Resulting irregular interfaces between layers, a common problem in commercial production, are detrimental to the mechanical and optical qualities of the product.

Under the NSF industry-university cooperative research program, C. D. Han, at the Polytechnic Institute of New York, is working with scientists at Allied Fibers and Plastics Company. Han has now developed criteria for determining the coextrudability of two or more thermoplastic polymeric materials. Using the criteria developed by this research team, engineers can now avoid interfacial instability in multilayer film coextrusion. More specifically, it is possible to select (1) polymeric systems on the basis of their rheological properties, (2) optimal processing conditions, and (3) the best design of coextrusion dies to reduce the amount of waste product. Because of the recent increase in the cost of resins, minimizing the waste product will help reduce manufacturing costs.

Supercritical Fluid Extraction

Chemical manufacturing processes typically require that materials be separated at various stages. In some situations this separation can be a major part of the manufacturing expense, especially when highly pure products are required or when expensive processing chemicals must be recovered for reuse.

A relatively new area of research in separation processes is that of supercritical fluid (SCF) extraction. An SCF is a solvent that is slightly above its critical temperature and pressure—those conditions at which it changes phases between gas and liquid. Interest in this solvent has stemmed from several advantages that SCF extraction may have over more conventional separation techniques. For one thing, it is more energy efficient, particularly when compared to distillation. The fluid solvent can be separated from the extracted solute by variations in temperature and/or pressure. Nontoxic supercritical fluids such as the light hydrocarbons or carbon dioxide can often be used. Also, the transport properties of a supercritical fluid lie between those of a liquid and a gas. Thus diffusion coefficients are much larger than in liquid extraction systems.

Applications of SCF extraction are quite varied. They include decaffeination of green-bean coffee using supercritical carbon dioxide; desalination of seawater using carbon-11 and carbon-12 paraffinic fractions; regeneration of activated carbon with supercritical carbon dioxide; solvent extraction of coal using supercritical toluene and water; de-asphalting of petroleum fractions with supercritical propane/propylene mixtures; and the use of supercritical carbon dioxide as a scavenging fluid in tertiary oil recovery.

Robert C. Reid and his students at the Massachusetts Institute of Technology are obtaining data on the equilibrium solubility for solids in several of these supercritical solvents and are developing general predictive correlations for solubilities in supercritical fluids. In another project, J. M. Smith and his students at the University of California, Davis, are getting the basic rate information needed to model SCF extraction. Data from these investigators will permit a more rational design of separation processes using this kind of extraction.

Civil and Environmental Engineering

NSF's civil and environmental engineering activities include fundamental research in geotechnical engineering, structural mechanics, and a wide range of problems encompassed under water resources and environmental engineering. While these areas reflect major current emphases, the program can accommodate any significant problem in civil engineering.

Under the Earthquake Hazards Reduction Act, NSF also has an engineering research program to look at the way earthquakes affect buildings and to study how structures could be built or modified to minimize both damage and loss of life from earthquakes.

Construction is one of the largest activities undertaken by a community. The value of works constructed in recent years is estimated at more than $200 billion, about 10 percent of the United States' gross national product. Much of NSF-supported research focuses on the phenomena and systems used in the planning, design, construction, and use of structures—with the goal of improving the efficiency and economics of these processes. NSF is also exploring some less traditional areas, such as the possibility that research on problems in architectural engineering could increase productivity in the building industry.

The major area of geotechnical engineering primarily involves soil, rock, and snow-and-ice mechanics. All of these topics deal with natural materials, their resistance to various forces, and the consequent design of satisfactory structures using these materials. Such structures include the foundations of buildings, bridges, and dams; they can also be the rock through which tunnels are dug or holes drilled for purposes such as oil recovery. Current activity in soil mechanics centers on developing a wide range of stress/strain relationships for different materials and loadings. In rock mechanics the focus remains on how fractures start and propagate.

An exciting recent development in geotechnical engineering is the construction of a geotechnical centrifuge at the NASA-Ames facility in Mountain View, California, under NSF support. A centrifuge previously built for astronaut training is being radically modified and adapted to let geotechnical engineers test models of foundations or earth dams. The instrument will be able to spin a 3-ton model around a diameter of nearly 60 feet at a centrifugal force equivalent to 300 g. This will be the largest geotechnical centrifuge in the western world when completed in 1983; it will be available to all geotechnical engineering researchers.

Structural mechanics includes studies of structural materials; determination of loads on structures; methods of analysis, prediction, and control of structural response; and development and improvement of design procedures. Studies are also under way on the materials of construction, including steels and other metals, portland cement concrete, and wood.

An interesting development in the structural mechanics area is the use of controls—active or passive devices to counteract deflections or add forces to stabilize excited structures. These devices will find their greatest use in high-rise buildings, where deflections might otherwise be so great as to affect the use of those buildings during high winds. Considerable research is needed in this field to evaluate possible benefits and determine the effectiveness of various types of control systems.

In water resources and environmental engineering, research continues on soil erosion and sediment transport. In this, as in many other areas, there is a tradition of empiricism, with research providing the fundamental understanding behind that empiricism. An interesting project is in process in Pakistan, where a U.S. researcher, in cooperation with a Pakistani colleague, is conducting large-scale experiments on river mechanics in the Link Canals. These canals, built many years ago for irrigation purposes, present an opportunity for experiments on a large scale in a manmade "river." Use of an existing canal cuts the prohibitive expense that would otherwise be necessary to construct this kind of facility.

In wastewater treatment, important problems still exist, even in the activated sludge treatment process that is now almost universal. New research is making it possible to avoid some common problems, such as the bulking and foaming of sludges because of troublesome bacteria. Problems like this can put a city sewage-treatment plant out of operation, with consequent pollution of adjacent streams or lakes.

In the earthquake hazard mitigation program, studies fall into two classes. First, earthquake engineering studies are concerned with the forces an earthquake puts on a structure. This part of the program relies heavily on ground-motion studies throughout the world. Instruments are placed in areas of known seismic activity, and any new records collected are used to estimate what forces a structure would encounter if placed at one of those locations. There remains a great need for such data because very few earthquakes have ever been recorded by modern, in-place instruments.

A second research area is the response of structures to earthquake excitation. Here understanding has increased very rapidly as a result of NSF-supported research in recent years. A major current effort centers on an extensive series of tests done cooperatively by the United States and Japan. These tests of full-scale structures look at the relationship between how each building behaves under earthquake-simulated excitation. Complementary experiments show how models of that type of structure behave; this provides information needed to interpret future model tests. Work in fiscal year 1981 focused on a full-size, seven-story reinforced concrete structure, and the results are now being analyzed. Future tests will involve a steel structure.

In addition to the engineering aspects, NSF also supports research on the social, economic, and institutional consequences of reducing earthquakes and other hazards. Most responses to earthquakes have concentrated on structural improvements, either through construction according to new safety standards or retrofitting to maximize earthquake resistance. The early emphasis of research was on disaster responses by individual organizations. In recent years the emphasis has shifted toward hazard mitigation and preparedness, including the role of the mass media.

Origin, Strength, and Properties of Loess

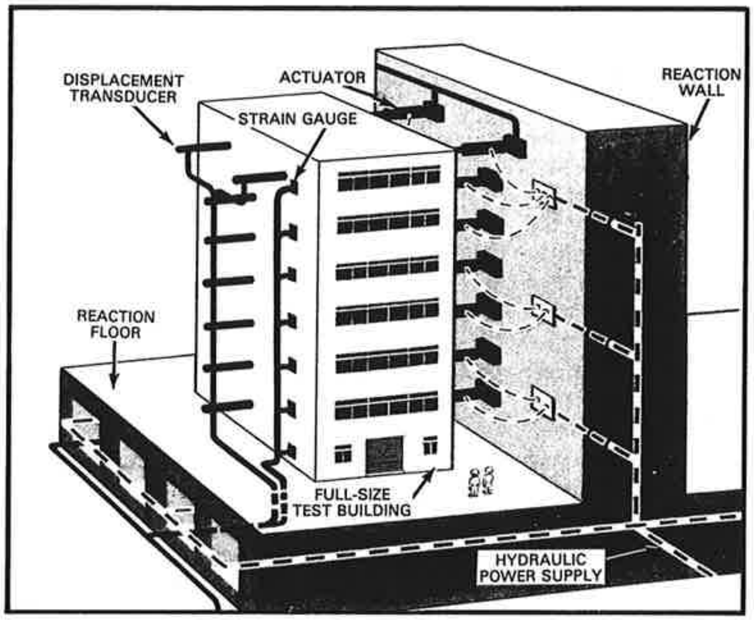
Loess, a porous, sometimes collapsible silt soil, is an abundant surface deposit—typically tens of feet thick—in many parts of the world, including the central United States, Europe, Russia, and China. Loess is believed to be derived from exposed sand bars of glacial outwash rivers and distributed across the landscape by wind.

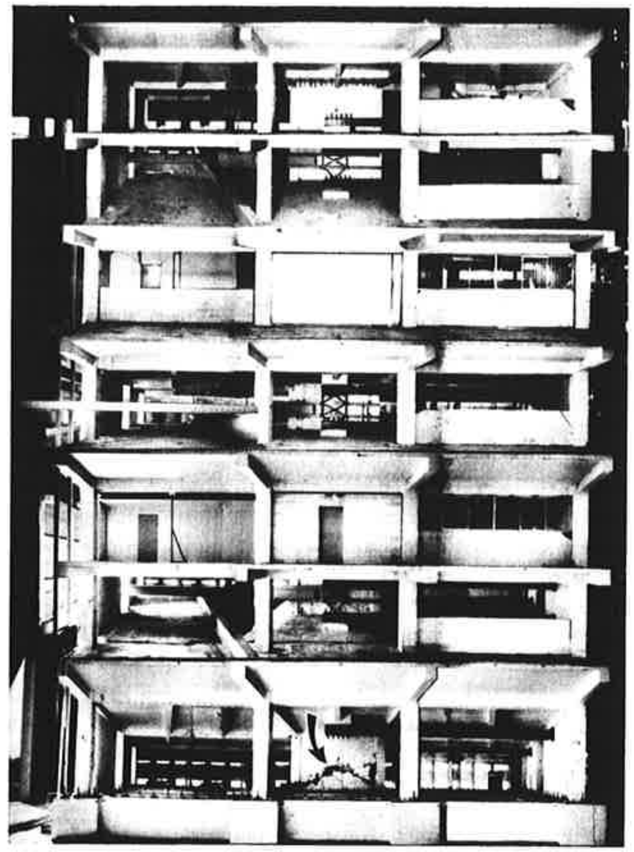
Richard L. Handy of the Iowa State University recently used computer modeling to examine a new eolian, or wind, distribution hypothesis for loess. The computer-generated data were then compared with field data obtained from test borings and analysis of samples in Iowa and Missouri.

These comparisons support the hypothesis of eolian deposition, with the attendant implication that loess engineering properties (structural strength and stability) may now be more intelligently and accurately predicted on a regional basis. The research has attracted international notice, and the principals have been invited to participate in a loess study in Bulgaria.

The loess depositional model involved the use of a statistical method known as the "random walk." The model that most closely fit field observations indicated several new insights. Empirical thickness and particle-size distributions for loess in relation to source areas are caused by randomly variable wind directions with a moderate prevailing wind component. It has therefore been concluded that the thick loess deposits adjacent to a source derive from winds blowing nearly parallel with it, not at right angles from the source, as previously supposed.

Transportation involves a combination of upward diffusion of particles by turbulent winds and gravitational sedimentation. This combination results in an approximately logarithmic relationship between thickness and distance. The increase in clay content with distance should be approximately semilogarithmic. However, sedimentation as discrete particles does not explain the observed changes in clay content. Transportation and sedimentation, therefore, are believed to have involved, in part, aggregates of particles. The *in-situ* shearing strength properties of loess, dependent on cohesion and internal friction, respectively increase





A shaking experience. The United States and Japan are jointly supporting studies of the response of full-scale structures subjected to simulated earthquake motions. The drawing shows how the strongback earthquake simulator at Tsukuba Science City, Japan, uses hydraulic actuators to apply pseudo-dynamic earthquake loading. The photograph shows the actual seven-story reinforced concrete building after testing (damage is indicated by the arrow at the bottom). This research is meant to confirm design practices, and data from these tests will be used to recommend better design and construction procedures.

and decrease with increasing clay content. Loess density also increases with depth.

The *in-situ* borings and tests associated with this last finding gave an unexpected bonus. A zone of liquid silt with a high water content was discovered at the core of many loess hills. This zone may explain unusual earthquake phenomena in the Kansu Province of China in the 1920s, when entire hills slid intact as far as one to three miles then suddenly stopped. It appears likely that the liquid silt phenomenon may not be confined to loess soils but could occur in alluvial and delta silts as well. This possibility broadens the potential importance of the hypothesis.

Earthquake Resistance: Full-Scale Testing

Earthquake-resistant design depends on knowledge of a structure's behavior under earthquake loadings. While theoretical and analytical studies have been progressing well and yielding useful results, experimental research in the field of earthquake engineering has been lagging. As a result, an understanding of the behavior of actual buildings has not developed as rapidly as desired.

To remedy this situation, a major cooperative experimental research program between the United States and Japan, involving pseudodynamic tests of large-scale structures, began in August 1979. This program will augment the results of theoretical, analytical, and numerical studies currently in progress. It will also validate scaling relationships and define the relation of component tests and analytical models to the response of full-scale structures.

The central feature of the cooperative program is the testing of a full-scale, seven-story reinforced concrete building, using the large structural testing facility at Tsukuba Science City, Japan. This facility can produce 4,000 tons of shear force and 72,000 ton-meters of bending moment at the base of the test structures. The latter are driven by large hydraulic actuators having load capacities of up to 100 tons and a maximum displacement of 1 meter.

In addition, the facility is equipped with a modern data-acquisition system capable of simultaneously recording data from 500 static strain gauges and 30 dynamic gauges. These, plus the on-line computer control system to simulate the dynamic earthquake loadings, make the facility unique for earthquake testing.

Under the joint program, the test-building specimen was designed by a U.S.-Japanese research team according to accepted earthquake-resistant design practices. The building was constructed at the Tsukuba test site, and the team has done a series of simulated earthquake tests. These range from linear elastic response (small displacement) and inelastic response to cracked yielding and beyond yielding (large displacement). In addition, supporting tests and correlation studies have been done simultaneously in both Japan and the United States.

Seven U.S. organizations (six universities and one industrial association) have been engaged in these supporting experiments, which included shaking-table tests of 1/4- and 1/10-scale model buildings and joints, wall systems, and other subassembly tests.

While the experimental data are not yet completely processed and analyzed, the research has already produced results that further the understanding of a building's response during earthquake excitations. For example, it has shown engineers how to design shear walls that would behave in a ductile manner by placing steel reinforcement around the boundary frame or elements. Component and subassembly system tests have also revealed that shear walls and beams cracked during testing can recover their original strength almost fully after repair by epoxy injection.

The full-scale testing in Tsukuba has dramatically verified the adequacy of current U.S. design and detailing practices for reinforced-concrete buildings. The building there was subjected to three large simulated earthquakes and survived with no major structural failures. Local bulking of beam bars at one location emphasized the need for careful detailing and construction inspection. Similarly, the lack of cracking and damage at other locations pointed out the conservatism of U.S. building codes, which require reinforcement at all locations.

The tests also showed that this pseudodynamic testing technique could be successfully used on a full-scale building. They provided data to verify and "fine-tune" existing analytical programs used to predict the dynamic response of reinforced-concrete buildings. Finally, the data gave information on the interaction between shear walls and frames within a structure.

The joint research has shed considerable light on the dynamic behavior of reinforced-concrete buildings subjected to earthquake loading. Engineers now know how to conduct simulated dynamic tests under laboratory conditions. It is clear that the procedure of pseudodynamic testing based on force or displacement control is sufficiently developed for use. Also, researchers have found that small-scale model tests are inadequate simulations of the true behavior of complete structural systems, which normally consist of complex floor-slab arrangements, various members and subassemblies, and complicated connection details.

In addition, the scaling relationships between small-scale and full-scale tests have been found to be nonuniform and nonlinear. These relationships are expected to be established more precisely after all correlation studies are completed. The joint program is now proceeding to its new phase—testing a steel building.

Mechanical Engineering and Applied Mechanics

These programs support basic research in areas ranging from the foundations of dynamics, the mechanical strength of solids, and fluid flow to the mechanical foundations of robotics, the theory of automated manufacturing, and nondestructive evaluation and testing. Within this framework, however, there are some major problems in mechanics that have resisted solutions for the past three centuries. These problems are now more amenable to solution, thanks to the powerful techniques emerging from mechanics and mechanical engineering research.

For example, in fluid mechanics, better understanding of turbulence and the transition to turbulence is beginning to emerge. Developments in bifurcation theory have been particularly useful in describing the phenomena associated with turbulent transition and flows. In addition, new insights into the classical Navier-Stokes equations will have consequences in many disciplines.

In heat transfer, new experimental and theoretical results in convection are giving valuable insight into the general characteristics of that class of phenomena. Studies of convection driven by density and species differences—and their interaction when the thermal and diffusive processes occur simultaneously—have been successful. These results are being used in attempts to study convection in multiphase processes.

In solid mechanics, the behavior of solids under multiaxial states of stress outside their elastic ranges is beginning to be understood. Some assumptions on the mechanical behavior of inelastic solids and in the classical theory of plasticity have recently been shown to be erroneous. Progress is now being made experimentally to determine the material-response factors shown to be essential to any complete theory with predictive capability. This is a significant step toward a true tensor theory of large-strain behavior of metals.

In production research, work on sensors for adaptive machining is progressing to the point where tool speeds and feeds can be automatically adjusted to maximize production, taking into account tool machine and workpiece conditions. In addition, research on industrial robots with vision capability is progressing to the point where applications to more complex assembly operations can be expected.

Thermal Convection in Cavities

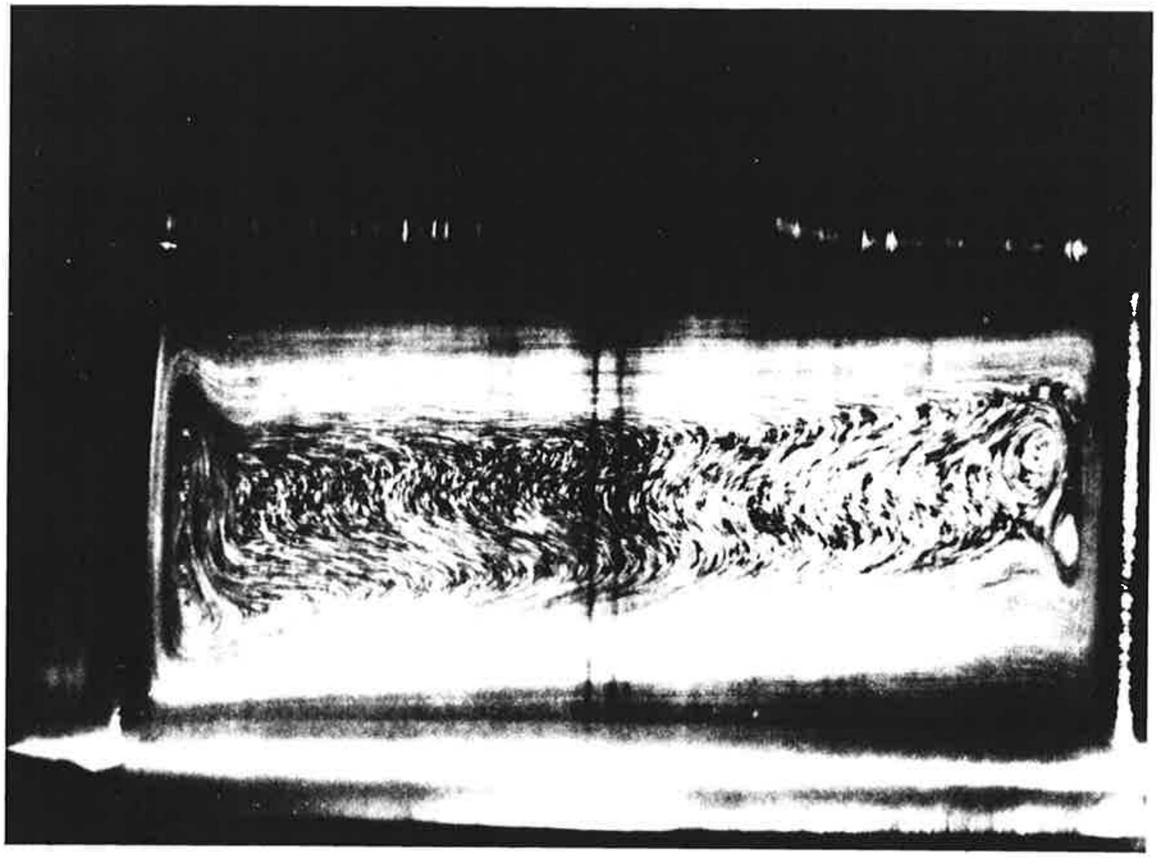
When a fluid is subjected to a horizontal temperature gradient (a regular change over some distance), the result is a corresponding density gradient and, subsequently, motion. The associated heat-transfer process is known as natural convection; it occurs by itself or in conjunction with other transport modes in many devices that are important in technological development. Compared to the understanding developed for other heat-transfer processes (such as conduction), natural convection is not well understood and cannot be predicted with accuracy in many instances. A number of complexities are responsible for this, including high Rayleigh number flows, variable fluid property effects, Prandtl number effects, complex geometries, transition to turbulence, and turbulent flows.

To address some of these issues, a joint university-industry research effort is being pursued by Philip A. Blythe of Lehigh University and Peter Simpkins of Bell Telephone Laboratories. Initiated because of problems connected with methods of growing crystals from melts in semiconductor materials, this combined theoretical and experimental investigation has been expanded to become a general study of natural convection in rectangular cavities. Typically, such a process is influenced by certain factors, including the geometry of the cavity and the Rayleigh number, which depends on the intensity of heating.

Now in its third year, the joint research has been directed toward the steady-state structure of fluid flows in cavities, driven by horizontal temperature gradients at large Rayleigh numbers. These flows are characterized by a vertically sheared and stratified core, surrounded by thin viscous and thermal layers on the cavity walls. It has been shown that the core structure is governed by interaction with the boundary layers on the vertical walls. The layers near the horizontal surfaces play a major role in determining the core structure at low or

Insulated wall

Hot wall



Cold wall

Insulated wall

Fluid flow. University and industry engineers conducting experiments at Bell Telephone Laboratories have been measuring the heat-driven movements of viscous fluids. Here, the flow of silicone oil is seen in a rectangular cavity with one vertical wall hotter than the other. This research—part of a joint effort by Bell and Lehigh University—adds to present knowledge of natural convection, a phenomenon less understood than conduction and other heat-transfer processes.

moderate Prandtl numbers. Melt flows associated with the growth of semiconductor crystals correspond directly to the low Prandtl number limit. However, the broad range of situations of interest in engineering covers a large Prandtl number range.

Blythe has examined the structure of the horizontal and vertical layers in the limiting case of an electrically conducting fluid. The horizontal boundary layers are found to have a two-zone structure, with convection and buoyancy important in the outer region and convection and conduction controlling the inner region. A method has been developed to calculate the interaction between the vertical boundary layers and the inviscid core, and results have been in excellent agreement with those generated by numerical solutions.

In the case of variable fluid viscosity, a transformation has been found that leads to a universal velocity profile. In general, the theory has shown that the horizontal structure is controlled by the limiting behavior of the core near the upper and lower boundaries. Boundary-layer approximations are found to be invalid for cavities of large-aspect ratios.

Current experimental work at Bell Laboratories has been concerned with measuring velocity profiles by a particle-tracking method and streak photographs of the flow field. From consecutive photographs, velocity profiles can be determined. Results confirm the validity of existing theoretical calculations based on boundary-layer flow approximations, but the measurements are for limited experimental conditions. Future efforts will include stability analyses of the flow and experimental measurement with laser speckle photography and laser Doppler anemometry.

Homopolar Pulse Resistance Welding

A new type of resistance welding, which promises to make possible the rapid joining of large cross-sections of metal, has been under investigation for the past three years at the University of Texas at Austin. This new process, known as homopolar pulse resistance welding (HPRW), uses a homopolar generator as a source of stored energy that is then released in coordination with the application of mechanical pressure to create solid-phase welds of the upset resistance type.

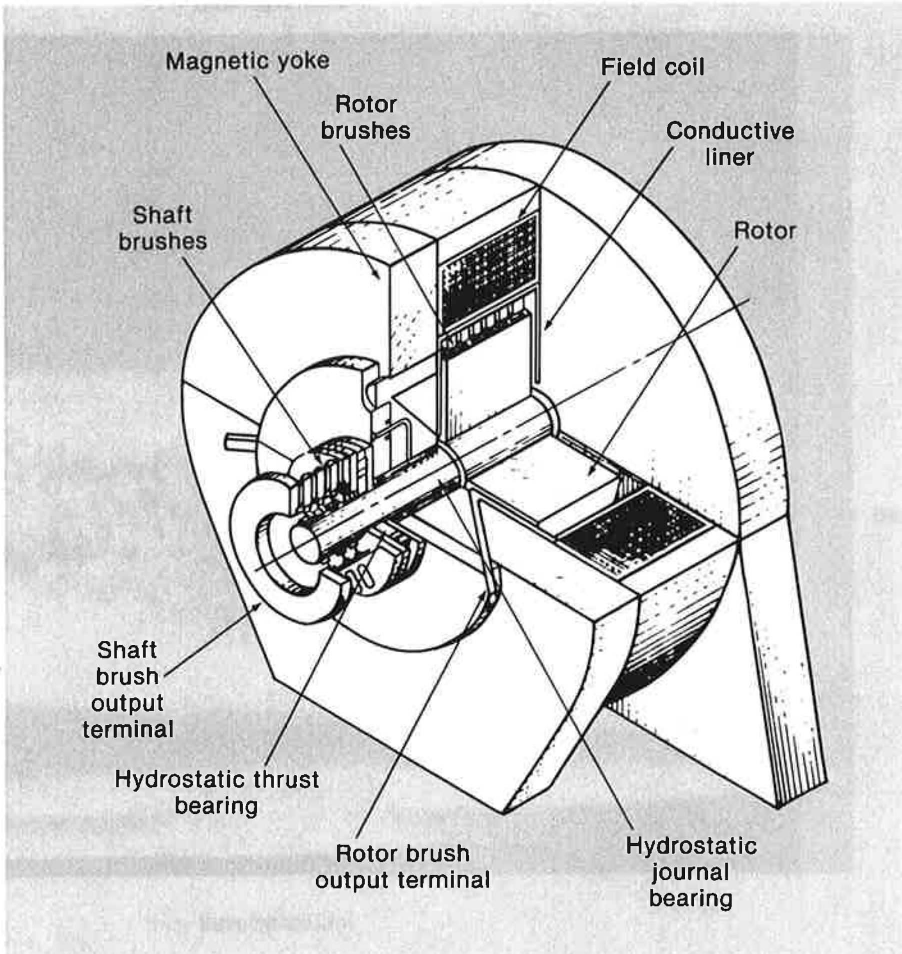
This process differs from other resistance-welding techniques in several respects; the most important is its use of the rotational kinetic energy of the homopolar generator's spinning rotor as the mode of energy storage. Because this stored energy can be built up in the rotor over a period of several minutes, the process requires a comparatively small prime mover, which can be any one of several types of motors or engines. Unlike other types of large-resistance welders, which impose a heavy power demand on the electrical distribution system, the output circuit of the generator in this process is not electrically connected to the power line.

The rotor, which serves both as a current conductor and as the energy storage element, is a right circular cylinder of alloy steel. In operation, the rotor rotates in an axial magnetic field created by the surrounding solenoidal field coil. Electrical contact between the rotor and the output circuit is made through sliding metal brushes on the rotor surface and at each end of the shaft. No current flows until a switch in the output circuit is closed, at which time a current pulse as large as several hundred thousand amperes is generated and lasts from one to several seconds. The shape of this pulse can be controlled by varying the comparatively small current in the field coil.

NSF has supported two investigations using the HPRW process. In the first of these, now complete, a broad survey was made of the electrical and mechanical requirements for welding a wide variety of alloys used in industry. The alloys studied included low-, medium-, and high-carbon steels, alloy steels, tool steels, stainless steels of the austenitic, martensitic, ferritic, and precipitation-hardening types, as well as such nonferrous metals as aluminum, molybdenum, titanium, and nickel-base alloys. In all, 19 different alloys were included in the study. Several dissimilar-metal pairs were also successfully welded; among these were stainless steel-to-carbon steel and stainless steel-to-aluminum.

Most of the welds during the first investigation were made using round bar stock, but some welds involved angle sections and small rails to show that the process is capable of joining parts with irregular shapes.

The second investigation has three separate objectives and is being cooperatively funded with the Federal Railroad Administration (FRA), the Ford Motor Company, and General Motors Corporation. The objective of the first task is to weld full-



Homopolar generator. Homopolar pulse resistance welding is a promising new, energy-efficient process for joining large cross-sections of metal rapidly and inexpensively. This is a cutaway view of a homopolar generator used at the University of Texas. The generator accumulates and stores energy in a spinning rotor; the rotor energy is built up over several minutes by a small motor. Homopolar generators may be a boon for the railroads and other industries in the near future.

size, high-carbon, steel railroad rails. For this task, the generator was rebuilt and upgraded, and a rail-welding fixture was designed and constructed.

During the second project, specimens of HPRW-welded rails are being produced for evaluation by the FRA and the railroad industry. If they prove superior to the welds now in use on many U.S. railroads, the HPRW process will be used to test welding in the field. The process is of particular interest to the railroads because of the national effort being made to rejuvenate the country's roadbeds. The new process seems to offer improvements in both speed and quality over existing field-welding methods.

The Ford Company is using the welding fixture built during the earlier project. Its aim is to study variables in the HPRW process so as to make seam welds in automotive body sheet steel. If such welds can be incorporated into automobile designs and made quickly, they could significantly influence body-manufacturing techniques.

For General Motors, specimens of bolt flanges welded to pipe are being prepared for evaluation. The specific application is for locomotive drive shafts, in which the flanges are now arc welded. This application is typical of those in which the HPRW process seems to offer substantial productivity improvement over present joining methods.

Pulsed electrical power has implications for industrial processes other than welding, such as heating, powder processing, and forming. The availability of generators that can deliver high-energy pulses at high-power levels offers exciting possibilities for future manufacturing methods.

Problem Analysis Group

NSF's problem analysis group identifies and analyzes key societal problems that have significant scientific content. The program gives a preliminary assessment of the appropriate role of science and technology, the federal government, and the Foundation in solving these problems. Many potential research topics and problems are analyzed in selecting research directions and priorities.

For example, NSF and the National Oceanic and Atmospheric Administration cosponsored a workshop on tsunami research opportunities in late 1980. Twenty-one scientists and federal officials addressed the problem of how improved research and technology could help predict the occurrence and magnitude of those potentially destructive sea waves, which are caused by seismic events. Their deliberations resulted in a comprehensive tsunami research plan published in September 1981. The plan suggests the following major areas for research:

- A tsunami observation program, including the design and development of instruments for measuring tsunamis along the coastline and in the open ocean.
- Instrumentation, telemetry, and data processing to permit real-time inference of sea-floor displacement and thus identify tsunamigenic earthquakes from seismic data.
- Theoretical and laboratory programs for fluid/structure interactions and the determination of structural design criteria.

The plan also stresses the need to create public awareness of potential tsunami dangers for the sake of emergency preparedness.

In other work, Anthony San Pietro of Indiana University conducted an international conference on biosaline research in La Paz, Mexico. The conference was supported by NSF in a joint undertaking between the United States and Mexico. Participants assessed progress and identified research needed to use salty environments to produce food, chemicals, and energy. They discussed salt as a stress factor in plant growth, potential uses of marine algae, salt-tolerant plants as sources of food and fiber, and future applications of marine and other salt-contaminated environments in the growth of salt-loving plants and microorganisms.

Interest and research in biosaline applications have grown rapidly in the past few years. The production of glycerol from cultured marine algae is being tested on a pilot basis, as is the recovery of salt-contaminated lands as grazing areas through use of salt-tolerant grasses. More research is needed to explain the way salt tolerance works in plants and microorganisms, to increase yields of useful substances, and to identify helpful salt-tolerant plants and grow them under field and industrial conditions. New genetic techniques are also needed to enhance salt tolerance and transfer that tolerance to sensitive species of plants and microorganisms.

The problem analysis group serves as executive secretary for a Coordinating Committee on Research on Intelligent Robotic Systems. This committee coordinates robotics-related work within NSF. It will explore new opportunities for interactions among NSF programs to encourage support of this rapidly developing field.

Studying—and preparing for—disaster. Tsunamis are destructive sea waves caused by seismic upheavals. These flattened parking meters show the direction and force of the tsunami that lashed Hilo, Hawaii in May 1960. In late 1981, a workshop and guide supported by an NSF engineering program suggested major areas for research to deal with tsunami disasters.

Biological, Behavioral, and Social Sciences

3

A striking feature of the research supported by NSF in the biological, behavioral, and social sciences is its diversity. Subjects studied range from ions to the Great Plains, from neurons to social groups. Between these extremes, items of scientific interest include one-celled organisms, insects, birds, mammals and fishes, microscopic plants, grains, trees, forests, and a host of others.

Despite the bewildering diversity, however, there is also unity. The scientists who study molecules are linked to those who study social groups through their focus on living matter—plants or animals—or artifacts of it. This common feature of the study of living things was broadened this year with the transfer of NSF's programs in information science and technology to this division.

One of the goals of information science and technology is to understand better how knowledge is represented, and electronic equipment and systems are used to serve researchers and communicate with humans. In this sense the links to other NSF programs are strengthened. Further, with manufactured electronic storage and retrieval components now approaching the scale of the neuron of the brain, computers are becoming analogs to human memory, recognition, and information processing.

Fiscal year 1981 saw extensive changes in NSF's programs in the biological, behavioral, and social sciences. From their beginnings in 1975, these activities remained fairly stable, with the addition and deletion of few programs, and they were generally able to increase the number of awards in response to the increased number of research opportunities. In mid-fiscal year 1981, however, there were extensive changes. Along with the addition of programs in information science and technology, all of the programs in this NSF division now became responsible for supporting applied as well as basic research. But other changes affected the existing programs as well.

In fiscal year 1981 steady growth slowed, and the number of awards made by old programs declined for the first time. In spite of increased budgets for physiology, cellular and molecular biology, and environmental biology, NSF was able to increase only marginally the number of awards for environmental biology; in the other areas there was actually a small decrease. Clearly, inflation is taking its toll in scientific research as elsewhere. There was a further impact in the form of recissions in the behavioral and neural sciences and especially the social and economic sciences. The results were substantial drops in the number of awards made by these programs and a reappraisal of those activities. For the future, NSF will concentrate on assuring the quality and continuity of critical national data bases and establishing a credible and balanced investment among theoretical, methodological, empirical, and practical work in these fields.

The 1980s, with their rapid developments in biotechnology, have already been characterized as the "decade of biology." They promise a host of important scientific and practical advances. This success story, building on many years of fundamental research in biology, reaffirms the vitality and critical role of the basic research long supported by NSF. The national investment in basic research is likely to be returned many times over by expected growth of the young biotechnology industry.

Biological, behavioral, and social sciences research remains strong and vital across the board. Two recent Nobel Prize winners in economics, Lawrence Klein at the University of Pennsylvania and James Tobin at Yale, have received long-term support from NSF. The three winners of this year's Nobel Prize in physiology and medicine, Torsten Wiesel and David Hubel at Harvard, and Roger Sperry at the California Institute of Technology, were supported primarily by the National Institutes of Health but have also been principal investigators on NSF projects. Recognition of their major

Table 3
Biological, Behavioral, and Social Sciences
Fiscal Year 1979, 1980, and 1981

(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Physiology, Cellular and Molecular Biology	1,344	$ 62.29	1,487	$ 67.20	1,484	$ 78.23
Environmental Biology	685	33.95	717	37.79	753	41.05
Behavioral and Neural Sciences	783	33.07	842	35.39	744	35.26
Social and Economic Sciences	460	25.39	518	26.64	489	25.10
Information Science and Technology	*	*	*	*	59	5.94
Total	**3,272**	**$154.70**	**3,564**	**$167.02**	**3,529**	**$185.58**

*Included under Scientific, Technological, and International Affairs in FY 1979 and FY 1980

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

contributions in understanding how the brain works is timely, since their research underpins the current vitality of the neurosciences.

This outside recognition of the type of research supported by the biological, behavioral, and social sciences is significant, but it is only a partial indicator of their vigor and importance. Other measures might be more representative. For example, in a large number of programs many—and in some cases most—of the articles published in prestigious journals are based on NSF-supported research. The influence of these programs is broad and deep in the scientific community and visible to the public in prestigious awards.

Research reported on the following pages presents only a small sample of the work supported. It demonstrates that while 1981 has been a transition year, programs in the biological, behavioral, and social sciences remained strong and fulfilled their essential role.

Physiology, Cellular and Molecular Biology

The history of most biological disciplines begins with a descriptive phase, principally at the level of structure. This is followed by empirical investigations of functions, and then by predictive testing. Thus the grand period of anatomy (the structural phase) at the close of the past century gave way to the flowering of physiology (the functional) in the early decades of the present century.

Against this general background, advances in methodology and instrumentation have permitted this formal structure/function approach to be extended to different levels of organization, beginning with the whole organism and ranging in modern times down to the level of the genetic material (DNA) in the chromosome. At each level there has been a search for mechanisms that operate there, as well as for the linking mechanisms between one level and the next higher one (as, for example, how cell types contribute to tissue organization and function).

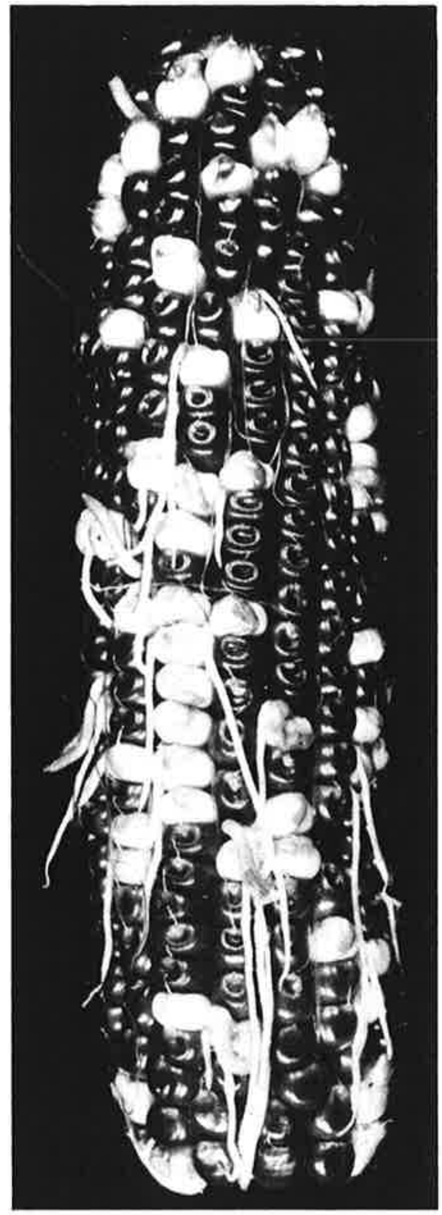
Current research centers around the mechanism through which the DNA segments called genes are able to express themselves and direct the biosynthesis of proteins. The process involves components that receive information in the cell membrane, cytoplasmic systems that transfer stimuli through the cell to the nucleus, and, in the nucleus, transformation of that stimulus into specific gene activity.

The biologists' new ability to devise molecular probes—through technologies such as recombinant DNA, monoclonal antibody production, and binding proteins—has permitted the beginning of yet another new inquiry on function. It is an interesting paradox that, having worked from the organism through tissues and cells to the molecule, we are now using molecules to retrace our steps and gain a better understanding of other hierarchical levels of functions.

Hormone Reception in Corn Ears

When the seeds of plants mature, they enter a period of arrested development and remain in a quiescent or dormant state until they germinate. Considerable evidence now implicates abscisic acid (AbA), a plant hormone that accumulates naturally in seeds during their development, in the cessation of growth and development.

Investigations in progress by Ian Sussex at Yale University are designed to show how AbA acts within the cells of developing seeds. His work centers around a series of viviparous mutants of corn. In these mutants, several of which have been isolated and genetically characterized by corn breeders, the seed does not become developmentally arrested; rather, the embryo germinates prematurely and grows into a seedling while still attached to the ear. Sussex has already shown that seeds of a particular mutant, viviparous 1 (*vp* 1), contain as much AbA as do normal seeds, and that the rate of metabolism of AbA is the same in mutant and normal seeds. Therefore, this premature germination cannot be explained by the absence of AbA or by different rates of metabolism of AbA in the mutant and normal seeds.



Mutant corn. This ear of corn displays normal (dark) and mutant *vp* 1 (light) kernels. In each *vp* 1 kernel the embryo has germinated prematurely into a seedling with elongating roots and shoots. Embryos in the normal kernels are developmentally arrested. Work with the mutants is helping biologists unravel the complex molecular activities of plant hormones. More knowledge in this area will benefit farmers and others interested in plant growth and development.

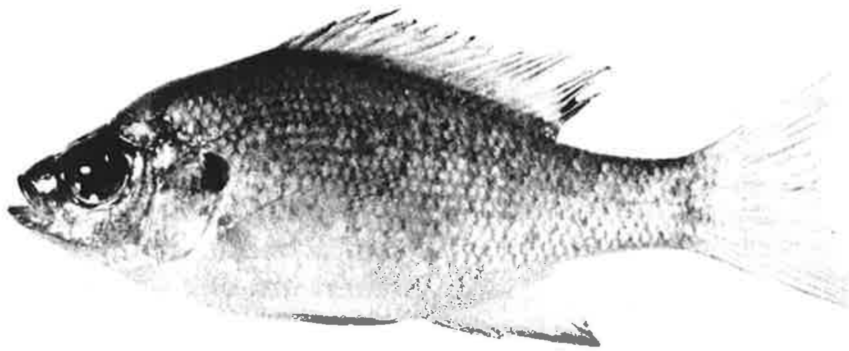
When embryos are removed from developing seeds and grown in sterile culture, those of the mutant *vp* 1 are 10 times less sensitive to AbA added to the culture medium than are embryos of normal corn.

Sussex proposes that the diminished sensitivity of the mutant embryos to AbA causes their premature germination and results from alteration in a hormone-binding receptor that is specific for AbA.

Early experiments to test this hypothesis revealed an AbA-binding receptor in cells of normal corn embryos and diminished binding of AbA to receptors in *vp* 1 mutant cells. Later experiments are designed to show whether the diminished binding of AbA to receptors in mutant cells is the result of a decreased number of receptors or a decreased affinity of mutant receptors for AbA.

The practical importance of these investigations is that AbA is critical in the induction, maintenance, and breaking of developmental arrest in seeds; it is also involved in the response of plants to water stress, cold stress, and osmotic stress. These are all growth phenomena that are basic to plant productivity. In addition, it has recently been shown that AbA is not specific to corn but also stimulates the synthesis of seed proteins in beans, rapeseed, wheat, and cotton. Thus, elucidation of AbA's mode of action could show us how to modify the accumulation patterns of seed proteins and improve the nutritional quality of food crops.

These and other investigations promise to help solve urgent practical problems and give fundamental insight into the complex molecular events involved in hormone actions.



Bluegill fish. These teleost fish are eaten by human beings and by predatory fish such as bass. The brains of bluegills and related species are being studied to reveal how hormones and their receptors may have changed during evolution. Such changes in hormone-receptor interactions may have a profound impact on our ability to regulate fish reproduction.

Hormone Reception in the Brain

The reproductive physiology of fishes is regulated by interactions between hormones and their receptors on target tissues, a process common to all vertebrates. Hormonal factors from the brain's hypothalamic region coordinate the secretion of pituitary hormones, such as gonadotropins, which in turn determine gonadal function.

The interlocking structures of receptors and hormones have apparently changed during vertebrate evolution. The resulting species specificity has confounded research attempts to use available, well-characterized mammalian pituitary gonadotropins to regulate fish gonads; receptors in these reproductive tissues seem to recognize the mammalian hormones poorly.

The structure of the pertinent mammalian hypothalamic hormone (called luteinizing hormone-releasing hormone, or LH-RH) has been determined. Joe W. Crim at the University of Georgia has noted that the structure of LH-RH is simple (small peptide) compared to the gonadotropins (glycoproteins containing both protein and carbohydrate) that they control. Under his hypothesis that structural simplicity may confer relatively conservative limits to evolutionary processes, Crim is studying the comparable gonadotropin-releasing factor ("LH-RH-like") of the fish brain to see how the hormone-receptor relations of fish and mammals have diverged.

Two general types of investigation are underway in Crim's laboratory to reveal the nature of fish LH-RH. First are studies to identify the receptors in fish reproductive tissues that recognize the pituitary hormones. Individual fish treated with fish brain extracts or with mammalian LH-RH exhibit varying reproductive responses; these indicate the biological activity of the pituitary gland and therefore receptor activity. Techniques for directly examining how LH-RH binds to receptors are also being developed for isolated fish pituitary membranes. Information from such procedures gives clues both to the character of hypothalamic factors and the nature of pituitary receptors.

Crim is also using antibodies, which are a kind of "receptor protein" of the immune system and exhibit a binding specificity like that of hormone receptors. Antibodies that bind to mammalian LH-RH are being used as probes both to measure amounts of fish brain extracts and to locate mammalian-like immunoreactivity within tissue sections of fish brains. Individual neurons containing LH-RH can be identified, and the status of these cells can be estimated by the strength of the staining involved. Extension of these studies from the descriptive to the experimental level is an exciting development.

The relationships between phylogeny and the presumed conservative evolution of hormone/receptor complexes are being judged in Crim's group by comparing experimental species. Of primary importance is a representative teleost fish, the bluegill *(Lepomis macrochirus)*. Comparisons to its phylogentic relatives, the bowfin (*Amia calva*, a more primitive fish) and the bullfrog (*Rana catesbeiana*, a more recent vertebrate), will give hints to any evolutionary changes. Knowledge of changes from the mammalian structure-function relations is essential in plans to control fish reproduction by intervention at the pituitary level, instead of at the gonadal level. If this peptide hormone/pituitary receptor evolution has indeed been conservative, then changes likely will have been few—but of great functional importance where they now occur.

Chromosome Modification and Gene Activity

How are genes expressed in a regulated way? This is one of the most exciting and important questions in genetic biology. A partial answer has been found by studying simple cells. Bacteria are single-cell organisms that carry their genes on a ring of DNA which is not separated from the rest of the cell by a membrane and in which the coding portion of a gene is uninterrupted. Regulatory factors within the cell affect the genes directly.

In more complex cells, however, DNA is separated from the rest of the cell by a membrane, and the coding portion of a gene can be interrupted by noncoding parts. Moreover, the genetic apparatus embodies a number of specific proteins as well as the DNA itself. Thus it is not surprising that knowledge of the mechanisms for regulating the bacterial genome (the complement of genetic material in the cell) was insufficient to explain the regulation of more complex genomes. We now know that several factors must be involved in the regulation of gene expression in complex cells.

Since the genome of complex cells is composed of DNA and proteins arranged in an ordered manner, does this higher order of organization change subtly as a way to expose or hide genes from the enzymes needed for expression? Are there other specific proteins that associate temporarily with specific genes to act as regulators? Is the DNA itself changed so that a gene may be expressed? Do all these possibilities have a role to play?

At the Hutchison Cancer Center in Seattle, Washington, Mark Groudine and Harold Weintraub have been asking questions about gene regulation in higher cells for many years. Their work supports the conclusion that the answers to the above questions are all affirmative. Recently they have exploited a finding by another laboratory that some chicken-cell genomes contain two DNA sequences related to the DNA sequence of a virus that infects birds. The chickens under study, however, do not show signs of the virus, because only one of the two DNA sequences is expressed. The sequence that is not expressed has methyl groups attached to some segments of the DNA. The equivalent regions in the expressed sequences are unobstructed.

Groudine and Weintraub have been able to show that by tricking the chicken cells into undermethylating the DNA in the nonexpressed sequence, they could induce the expression of that previously silent gene. Thus it is now widely accepted that the degree of methylation of the DNA segments that comprise a gene in some way affects the expression of that gene. From partial answers like these come the beginnings of solutions to the riddle of gene expression.

Chromosomes, Mitochondria, and Mammalian Cell Hybrids

Mitochondria are semiautonomous cell components that are involved with energy metabolism. These tubular structures contain genetic material in the form of a closed, circular molecule of DNA. Lively research has centered around the question of to what extent the replication and activity of mitochondria are controlled by genes in the mitochondrial, rather than the nuclear, DNA.

This important question is tied to a new and fast-moving line of research. Mammalian cells derived from one species can be fused with cells from another species when they are grown in cultures. When these hybrid cells are constructed by fusing human tissue cells with mouse tissue cells, each hybrid cell at first has a full complement of chromosomes from each species. During successive divisions, hybrid cell lines tend to segregate, or eliminate, chromosomes from one species and maintain the full complement of chromosomes of the other type. Whether human or mouse chromosomes will be segregated depends on the specific cell lines used in the cell-fusion experiments and, in some cases, on the incubation conditions of the hybrid cells.

Various experimental conditions can be manipulated to obtain hybrid cells that maintain human and segregate mouse chromosomes, maintain mouse and segregate human chromosomes, or maintain a full complement of chromosomes of both types. In the last of these three types of hybrids, human chromosomes are stable, mouse chromosomes are lost very slowly, and most cells maintain a complete set of both types of chromosomes.

It has been observed that there is a relationship between chromosome and mitochondrial DNA (MtDNA) in this segregation process. That is, if a hybrid cell line tends to lose mouse chromosomes, it also loses MtDNA derived from mouse cells and maintains MtDNA derived from human cells. What regulates these events? Does maintenance of MtDNA in hybrid cells depend on the presence of a companion chromosome or set of chromosomes? Is an imbalance of chromosomes from the two species responsible for loss of one type of MtDNA? Or is some other regulatory mechanism responsible for the correlation between chromosome and MtDNA segregation?

To answer these kinds of questions—which bear directly on the basic relationship between the two types of DNA in a cell—techniques have been developed to determine (1) the complete chromosome sets of hybrid cells, (2) the activities of genes and coding for specific enzymatic protein variants (known to be located on specific chromosomes), and (3) the proportion of MtDNA in hybrid cells derived from mouse or human parental cells.

Results from these kinds of experiments are reported by Laura de Francesca, Giuseppe Attardi, and Carlo Croce at the California Institute of Technology. They can be summarized as follows:

- Mitochondrial DNA of the species whose chromosomes were segregated from the nucleus was absent or present in marginal amounts in hybrid cells. That is, only MtDNA from the cell whose chromosomes were stable was maintained. It seems there is no specific chromosome whose absence is responsible for the failure of hybrid cells to maintain one type of MtDNA.

- In some cases most of the cells in the population had the full complement of segregating mouse chromosomes as well as a full complement of stable human chromosomes, but they still lost all MtDNA derived from mouse cells. Also, the stable set of chromosomes does not completely suppress gene expression in the segregating chromosomes.

- Apparently, stable chromosomes somehow selectively suppress the segregating chromosomes, allowing the expression of certain genes but suppressing others. The mechanisms by which one set of chromosomes regulates the expression of genes on another set are now being investigated, using the elegant experimental system provided by hybrid cells.

Nitrogen Fixation in Legumes

A major factor in the yields of modern agriculture has been the steady increase in the use of nitrogen fertilizers. But industrial manufacture of nitrogen fertilizer requires large amounts of precious natural gas and petroleum reserves for its high-temperature/high-pressure process. Predicted increases in the cost of nitrogen fertilizer will present an acute economic problem for American agriculture and will prevent the expansion of food production in many less-developed countries.

The fertilizers provide plants with chemically combined (or "fixed") nitrogen in the form of nitrate or ammonia. The plants then convert these chemical forms into protein, which humans and other animals consume to fulfill their own nitrogen requirements.

In contrast to plants and animals, a highly specialized class of bacteria is able to convert directly nitrogen gas from the atmosphere to ammonia, using complex enzymatic systems. Some of these "biological nitrogen fixers" establish symbiotic relationships with plants, such as soybeans, exchanging surplus ammonia for food and a protected habitat. Such symbiotic associations enable the host plants to grow without added nitrogen fertilizer.

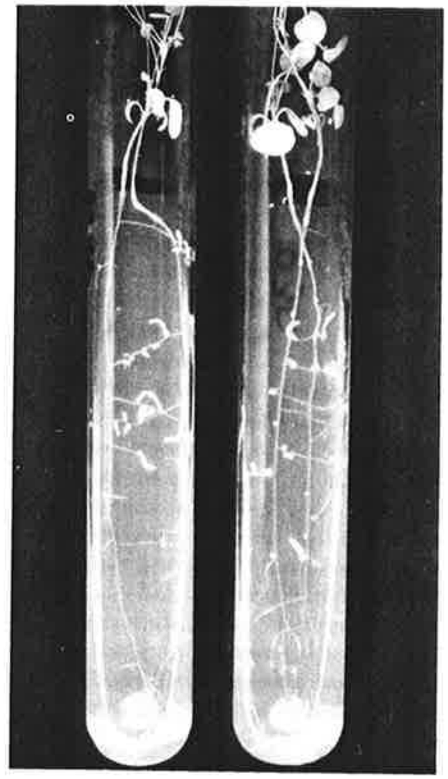
The symbiotic relationship between the bacterial genus *Rhizobium* and leguminous plants (soybeans, alfalfa, clover, peas, etc.) has long been of particular interest to agriculture. Nitrogen fixation in legumes takes place in root nodules, intricate and highly specialized structures formed when the bacteria invade individual cells inside the legume root. Because of their nitrogen-fixing endosymbionts, legumes thrive in nitrogen-depleted soils and will even enrich the earth with surplus organic nitrogen. With a full understanding of the complex relationships between *Rhizobium* and legumes, it will be possible to breed new varieties of legumes and select new *Rhizobium* strains with enhanced nitrogen-fixing abilities.

Frederick Ausubel at Harvard University is working to elucidate the developmental genetic pathway leading to the formation of symbiotic nitrogen-fixing nodules by *Rhizobium meliloti* and alfalfa. Bacterial genes control many of the steps in this process, and several of these steps have been identified by isolating mutant bacteria that are unable to establish a symbiotic relationship. In this way Ausubel has identified *Rhizobium* genes necessary for the *Rhizobium* and plant to recognize each other, genes needed for the *Rhizobium* to change into the nitrogen-fixing form, and genes necessary to carry out the nitrogen-fixing reaction.

Ausubel has also developed novel recombinant DNA procedures to identify, clone, and manipulate the *Rhizobium meliloti* nitrogen-fixation and symbiotic genes. He has used these methods in combination with well-established microscopic techniques to correlate the structure and function of the nitrogen-fixing nodule with the underlying genetic information.

Many of the genes in *Rhizobium* that control or influence symbiotic nitrogen fixation seem to be at sites scattered throughout the bacterial chromosome; however, these genes may control general bacterial "fitness" rather than having a specific function in the symbiosis. In addition to finding such chromosomal genes, Ausubel has discovered that several specific genes used in symbiotic nitrogen fixation (including genes for host invasion and for the enzymes that actually catalyze nitrogen fixation) are linked together in one region on an extremely large plasmid (a separate, ringlike piece of DNA) common to all *Rhizobium meliloti* strains.

These genes for symbiosis and nitrogen fixation have been cloned. The clustering makes it possible to clone several closely linked genes in a single process; this may make it possible to transfer the genes as a group into other bacterial strains. The new knowledge will indicate how to improve existing symbiotic associations and may also help extend the use of this process to other agricultural systems where nitrogen availability is a critical limiting factor in yield.



Forming a nodule. These nodulated alfalfa plants are growing in a test-tube medium. The "bumps" on the roots are nitrogen-fixing nodules formed by the interaction of a bacterium ***(Rhizobium meliloti)*** and the alfalfa roots. That interaction enables the plants to grow without the expensive nitrogen fertilizer typically used in modern agriculture. New research in this area in using recombinant DNA techniques to isolate and clone ***Rhizobium*** genes involved in nitrogen fixation. Continued progress could revolutionize agricultural practices.

Environmental Biology

Projects supported in environmental biology seek to show the interrelations of the some 4.5 to 5 million species of living organisms. There are two basic approaches, systematic and ecological. Environmental biologists motivated by systematic interests study the basic affinities among the varieties of life. Ecologists and ecosystem scientists, on the other hand, study the dynamic relationships of the organisms that live together in a hierarchy of systems—populations, communities, ecosystems—that together comprise the biosphere.

Each approach requires the examination of different nonbiological aspects of the biosphere. Understanding the systematic affinities of the living species of a major taxonomic group often requires consideration of the rock formations that are the foundation of the biosphere itself. Many of these rock strata contain the remains of once-living creatures and preserve to varying degrees the structure of the original organism.

Ecologists need to know something about the chemistry of the rocks underlying an ecosystem, but they are more often concerned with soils and aquatic sediments, the hydrosphere, and the atmosphere. Each of these parts of the biosphere affect, and are affected by, the living parts. For example, soil provides nutrients to terrestrial plants through their roots, but the composition of the soil is at the same time affected by the return of organic material to it.

Even the atmosphere is modified by the earth's biota. Oxygen, absent from the earth's original atmosphere, became a dominant component when, relatively early in the earth's history, green plants began to use sunlight in the manufacture of carbohydrates. The by-product, oxygen, accumulated in the atmosphere. Ecosystem scientists, examining how living matter modifies the atmosphere today, focus on the biogeochemistry of carbon, sulfur, and nitrogen. All have gaseous phases and all affect human welfare—notably through the "greenhouse effect" of increased atmospheric carbon dioxide and possible shifts of climatic zones, through acid rain, and through ozone control of the penetration of ultraviolet radiation to the biosphere.

It has become obvious that short-term projects cannot provide the information necessary to assess the role of the biota in modifying such slow changes in the atmosphere. These projects have also proved inadequate for the study of many biological processes that are slow to run their course. For that reason, in 1981 NSF began initial support of a network for long-term ecological research. Six active projects, originally funded in 1980, were joined under a steering committee charged with overseeing the development of network characteristics, such as data comparability and joint experiments.

The projects, located at six separate field sites and administered through six different academic institutions, represent major ecosystem types within the United States—deciduous forest, coniferous forest, alpine treeline and tundra, tall-grass prairie, freshwater lakes, and tidal estuary and marsh.

Ecologists expect to gain a better understanding of the specific ecosystems and to study the effects of environmental phenomena that span regions or the whole continent. Among the subjects to be studied are drought, acid precipitation, atmospheric carbon dioxide enrichment, and accumulation of toxic compounds.

Three recent projects reveal new facets of the life of green plants within the complex ecological systems they dominate. It is a truism that the photosynthate they produce in sunlight is the energy base for that entire system. But the totality of vegetation also establishes the living volume of an ecosystem, its peculiar architecture, and, indeed, the kind of soil in which it is rooted. Terrestrial plants achieve rigidity, hence size, by converting part of photosynthate into complex, chemically inert structural molecules.

One study follows the immediate fate of photosynthate in a plant exposed to light. The second project examines a subtlety of the age-old chemical warfare between plants and the animals that continually try to use the photosynthetic apparatus—leaves, primarily—as food. The third assesses the significance of plant-structure remnants and other so-called organic matter for the continuing productivity of prairie soils.

Translocation of Photosynthate in Plants

Carbon fixation, use, storage, and transport through plants is a major component of ecosystem function and dynamics. Understanding the exchange of carbon between plants and the atmosphere has reached a high level of development. Likewise, biochemical studies of the products that are formed offer excellent information on how carbon is used by plants.

Transport of carbon within plants, however, is more difficult to measure. Time-course studies of changes in pool size or movement of carbon-14 have been useful, but the need to destroy plants to analyze them limits progress in understanding how the environment controls the allocation of carbon in plants. Now scientists at Duke University and Texas A&M University have developed a system in which the carbon-11 radioisotope can be photosynthetically incorporated (as carbon dioxide) into intact plant leaves and instantaneously and continuously measured as it circulates through the plant.

Carbon-11 is a gamma-emitting isotope with a 20-minute half-life. Its location and rate of movement can be simply detected without the need for destructive sampling. Moreover, scientists can perform simultaneous experiments with carbon-11, -12, and -14, and with nitrogen-13, -14, and -15.

A recent comparative study of carbon allocation involved *Abutilon theophrasti* (velvetleaf), a plant from Mississippi and Wisconsin populations. Exploratory experiments had suggested that the larger, faster-growing plants from Wisconsin have lower total translocation resistances than the smaller plants from Mississippi. These crude results were confirmed and substantially refined in an experiment at the Duke University Phytotron. There translocation rates and allocation patterns of the carbon were continuously and simultaneously measured relative to the plant's net photosynthesis. Thus, for the first time, scientists can get real-time measures of carbon allocation simultaneously with net photosynthesis and transpiration measurements.

Digestibility Reducers

The chemical defenses by which terrestrial plants deter herbivores have been examined intensively over the past decade, and NSF has supported much of the research that involves nonagricultural plants. These studies have shown that plants contain complex molecules that have either of two effects on herbivores ingesting them. One effect is outright poisoning; many taxonomically unrelated plants have evolved "toxins" with a wide variety of chemical structures. Although systematically diverse, the species that produce toxins share similar ecological relationships—they tend to be small-sized plants that occur in open plant associations as widely dispersed individuals or in small clusters. The other effect, digestibility reduction, often involves the tannins or resins that occur in most trees of stable forest association.

Peter Price and his associates at Northern Arizona University, among others supported by NSF, have recently emphasized the importance of viewing these plant-herbivore interactions in the light of the larger community of which any pair is but a small part. The communitywide effects seem quite different for the two types of deterrents. A toxin, as has been known for some time, protects the plant species from most groups of insect herbivores. But, almost universally, at least one group has evolved a means of deactivating the toxin and has become a "specialized feeder" on that particular species. Some herbivore species have even developed ways to use the plant-produced toxin to defend themselves from their own carnivorous enemies—a community involvement.

The community context is significant in quite a different way for digestibility reducers. According to Price, the very efficacy of the deterrent compound depends on predation by the herbivores' enemies. Price has argued that production of a digestibility reducer, in and of itself, might be a self-defeating strategy for a plant. If the deterrent reduced the herbivore's benefit from its food, the partially starved herbivore might eat even more of the plant tissue. But the slow-growing, half-starved insect larva might be more vulnerable to its enemies; consequently, in nature the plant might actually sustain less herbivory.

Price designed a set of experiments to test these two possible outcomes. He used lines of soybeans that differ principally in the amount of tanninlike substances in their tissues. Into two cages he introduced an equal number of larvae of the Mexican bean beetle *(Epilachna varivestis)*. At the end of the experiment he found that the soybean with lower digestibility had indeed lost more leaf area to the insect larvae than had the plant with less tannin. This result confirmed Price's conjecture. The digestibility reducer, in slowing larval development, prolonged the period during which the immature insects feed.

Price then conducted a second experiment to approach "community" conditions by adding a predator in the form of a pentatomid bug *(Podisus maculiventris)*. Now the low-digestibility soybean, which had sustained greater leaf loss in the absence of predators in the first experiment, was increasingly spared as the number of predators per cage increased. At the highest predation level, the outcome of the first experiment was reversed. The investigators concluded, therefore, that digestibility reduction is successful for a plant when the herbivores are themselves subject to predation.

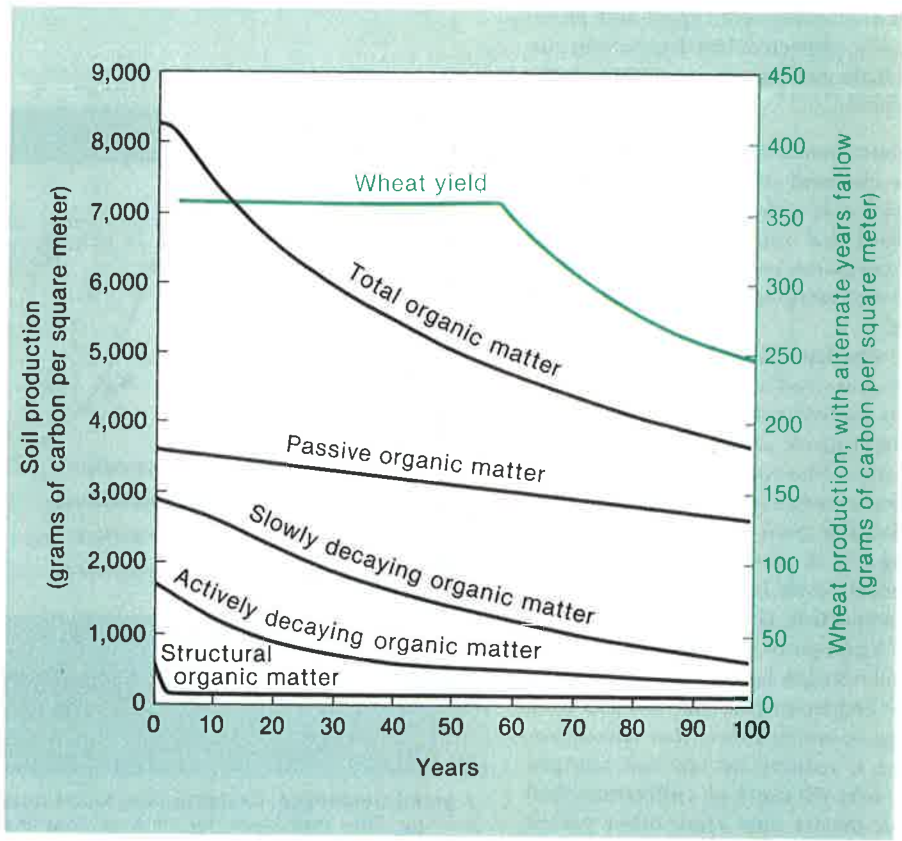
This finding lends support to the view that digestibility reducers are only effective in a natural community, where there is usually a high probability of predation upon the insect herbivores. Thus, while a toxin that protects a plant from most herbivores can be used by specialized feeders to deter their own predators, the digestibility reducers actually require predation on the herbivore population in order to protect the plant.

Dynamics of Organic Matter in Soil

Soil development—the accumulation of soil organic matter and essential nutrients—is a consequence of biological activity. Sustained biological productivity in turn depends on healthy soils. Nowhere is this biological dependence more clearly shown than in the semiarid Great Plains of North America. A large portion of this vast area has been cultivated for the past 50 to 100 years, and much of the remainder has been used as rangeland and native pasture.

Range and cropland soil resources, especially organic matter and nutrient content, have declined during the course of human activities in this area. Nonetheless, with improved management practices, including the use of adapted crop varieties, fertilizer inputs, and residue and water management, large areas are more productive than when native soil was first broken. The fundamental question, however, is whether this productivity can be maintained in the face of declining soil resources. This requires basic knowledge of the biotic and abiotic processes (and their interactions) that form and maintain soil. Scientists at Colorado State University are involved in a major project to address these issues in short-grass prairie ecosystems and agro-ecosystems.

The Colorado project involves a combination of experiments and computer models. Low-resolution, fairly simple models (century models) simulate the long-term (100- to 2,000-year) impact of different agricultural practices on the cycling of carbon, nitrogen, and phosphorus in the



Soil dynamics. With experiments and computer models, scientists at Colorado State University show a decline (in black) for organic matter in Great Plains soils after grassland sod was cultivated for wheat production. The simulated wheat yield (color) also dropped after 60 years because of low nitrogen levels in the soil. These projections help answer the key question of whether agricultural production can continue in the face of declining soil resources.

soil and the effect on crop yields. Higher-resolution models (annual models), with one-day time steps, simulate seasonal dynamics of the flow of carbon and nutrients in the soil-plant system.

The century model, for example, can look at the long-term effect of different agricultural practices on nitrogen and carbon in the soil system. Flows of the two elements in the model are similar, except that the carbon is accumulated in a carbon dioxide sink and the nitrogen in both a nitrogen sink and a mineral pool. The three soil organic fractions are as follows:

- An active fraction of soil carbon and nitrogen, mostly microbes and metabolites and humified organic matter, with a short turnover time of 10 to 20 years.
- A pool of carbon and nitrogen that is physically protected or resistant to decomposition and thus has an intermediate turnover time of 100 to 300 years.
- A chemically recalcitrant and physically protected fraction having the longest turnover time of 1,000 to 2,000 years.

Computer-model results were compared to the observed data for rangeland and cropped soils at Sidney, Montana. The simulated total organic matter after 8,000 years compares very well with the data (8,000 vs. 7,800 grams of carbon per square meter).

The simulated effect of cultivation of a native grassland under a wheat-fallow system showed a 45 percent decrease of total soil organic matter after 50 years of cultivation. Most of the decrease resulted from loss of active and slow organic matter. Simulated annual primary production during wheat years stays at maximum production levels for the first 60 years of cultivation, then slowly decreases to less than 70 percent of that value—a result of low soil nitrogen levels.

This finding is consistent with data from the region, which shows that wheat production is reduced by low soil nitrogen levels after 50 years of cultivation. Soil organic-matter data from other paired cultivated and virgin sites representing the different environmental conditions (temperature and soil moisture) across the Great Plains will be used to validate the models further.

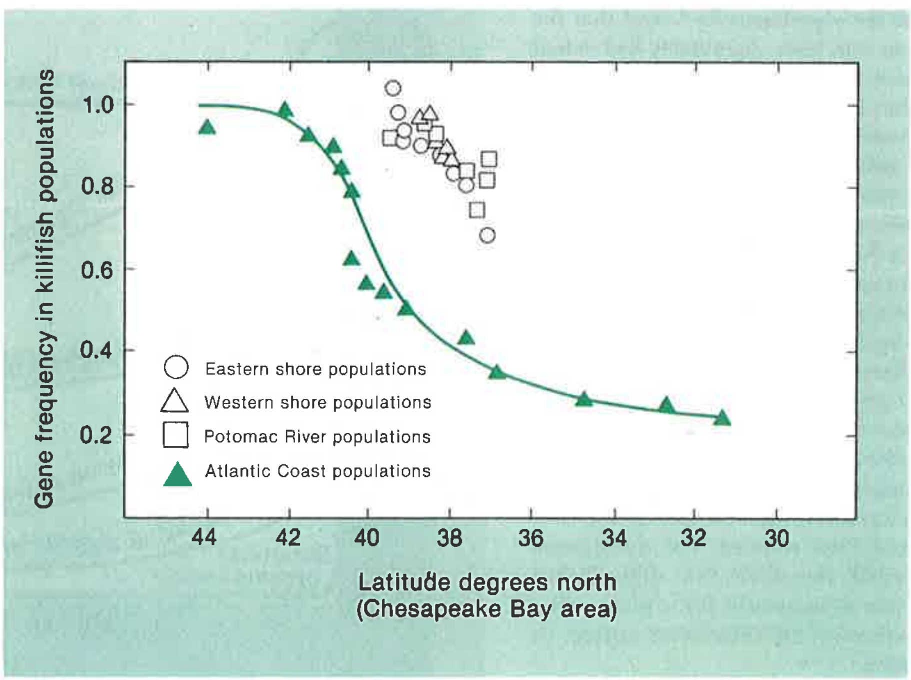
Genes, Physiology, Ecology—The Grand Connection

During the 1960s the development of electrophoretic techniques allowed biologists to inventory the genetic variability within and among plant and animal populations. Those and subsequent studies revealed unexpectedly high levels of genetic variability, and population biologists have been trying to understand the consequences of these variations for the ecology and physiology of living organisms. Studies currently conducted by Dennis Powers of Johns Hopkins University link genes with physiology and with ecology and thereby span the gulf between proteins and populations.

Powers studies killifish *(Fundulus heteroclitus)*, a hardy species found all along the Atlantic coast of North America, in both salt and fresh water. These fish often occur in shallow water and are thereby subjected to extreme changes in temperature on both a daily and seasonal basis. Their eggs are adhesive and attach to vegetation, and in certain populations the eggs are laid inside empty shells at high tide and the larvae develop out of water. In sum, these fish disperse only over short distances and are subjected to highly variable environmental extremes. They would, therefore, be expected to show adaptation to local conditions. These characteristics led Powers to investigate the relationships among genes, physiology, and whole animal biology.

Within the Chesapeake Bay there exist clear north-south variations in gene frequencies among killifish populations; this genetic variability, seen in differences among the enzymes produced by the genes, is paralleled by environmental variation of salinity, temperature, and oxygen tension. Powers analyzed the purified enzymes to characterize the activity of each one at different temperatures and salinities. By crossing individuals of known genotypes, he could also measure the performance of individuals that carry specific genes—and hence specific enzymes.

Powers has examined a suite of three



A grand connection. Biologists have found surprising links between genes, physiology, and ecology. They now know, for instance, that changes in such environmental conditions as temperature, oxygen levels, and salinity can affect the enzymes produced by a fish's genes. This chart shows north-south differences in the genes of killifish in the Chesapeake Bay and nearby Atlantic coast. ("Gene frequency" refers to the proportion of the population that has a certain characteristic—such as a specific enzyme—associated with a single chromosomal locus.) The clustering shown here seems to come from the isolation of these fish, which tend to stay in the same general area.

enzymes that have direct effects on the transport of oxygen across the gills; these enzymes thereby affect the activity of the fish at low oxygen tensions and under conditions of prolonged activity. He is now beginning to bridge the gap between how gene products (enzymes) act in the organism and how they affect individual performance.

Behavioral and Neural Sciences

The general objectives of behavioral and neural sciences research are to advance understanding of the biological, environmental, and cultural factors that underlie the behavior of human beings and other animals, with explicit emphasis on nervous system structure and function. Such studies require approaches and techniques that span research in the physical, biological, behavioral, and social sciences.

Five years ago NSF's programs in the behavioral and neural sciences were brought together in a single administrative unit. This attempt to establish a bridge between the biological sciences and the social and behavioral sciences has been largely successful. As shown in the descriptions of research that follow, work is proceeding at the molecular, cellular, system, individual, group, and cultural levels and may be described in three research clusters: neuroscience, cognitive science, and anthropological science.

Research in neuroscience seeks to describe nerve cell action, the growth and development of the nervous system, and the underlying anatomical, physiological, and biochemical bases of that system. Emerging knowledge of brain function and behavior now offers direct insight into how information from the environment is received, processed, and integrated by the nervous system and how behaviors—from simple reflexes to complex sequences—are generated. Progress at the cellular and molecular level has been especially rapid in recent years as scientists use new techniques to analyze individual nerve cells, their membranes, and molecular components.

Cognitive science focuses on how human beings obtain, store, retrieve, and use information; the general properties of language and how it is acquired and used; and the complex behavior of people, including development processes. Some approaches emphasize an understanding of individual behavior; others examine the group or organizational setting, focusing on better work performance and productivity. Progress on how language is acquired, how other cognitive behaviors develop, and how to identify key factors that influence cognitive development has been especially rapid.

Anthropology describes the laws or regularities that underlie human societies and populations worldwide. NSF supports research in cultural and physical anthropology, archaeology, and the preservation of (and improved access to) essential research collections. Current research, which integrates the biological, physical, and social sciences, gives perspectives on contemporary civilization across both time and space.

With the aid of a growing array of new dating techniques, archaeological research extends our knowledge into the distant past, while cross-cultural studies expand the view of our present world and the human response to such stresses as urbanization, scarcity of food and water, and greater population density.

The brief descriptions of research that follow are only a small sample of the many results emerging as the behavioral and neural sciences mature. Although relatively young, these areas of science have developed very rapidly and owe much of their current success to their multidisciplinary origins, which continue to foster powerful new approaches and technologies.

Behavioral Endocrinology

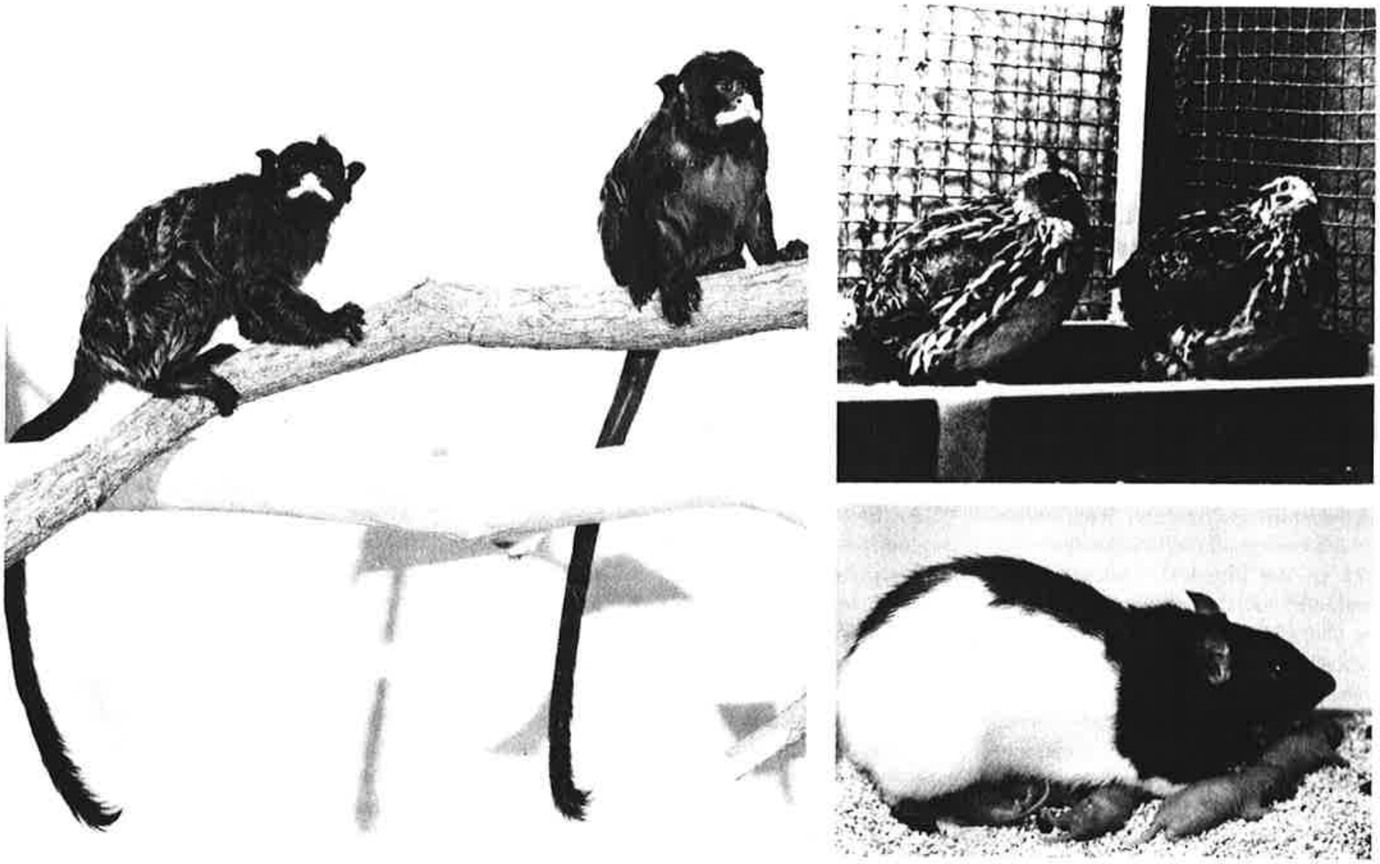
All living organisms have physiological mechanisms that determine behavioral responses to environmental conditions; hormones often make these behavioral responses more effective. This is best illustrated by the relationship between hormones and reproductive behavior. When seasonal factors are favorable for survival of young, there is a surge in gonadal hormone production. These hormones play roles in the courtship, mating, and parental behaviors necessary for the birth and survival of offspring. Two recent, important discoveries about the link between hormones and behavior are as follows: hormones may exert their effects on behavior long before that behavior is manifest, and behavior can affect hormone production.

With respect to the first of these, Elizabeth Adkins's studies at Cornell University show that brief exposure to sex hormones early in the fetal development of an individual dramatically and permanently influences the adult behavior of that individual. For example, in order for a female quail to act as a female in adulthood, her developing brain must be exposed to a steroid hormone, estradiol. If estradiol is not present at a critical period before hatching, the female develops male or neutral sexual tendencies in adulthood.

This link between hormone levels during development and adult behavior can be extremely complicated. Brief exposure to sex hormones early in development may affect the way an individual is perceived and treated by another, and this can have important consequences for later life. Celia Moore at the University of Massachusetts at Boston has shown that because a newborn male rat has circulating testosterone, his mother will recognize him as a male and will treat him differently than she treats his sisters. He needs the additional sensory stimulation she provides in order to perform normally in social situations when he is an adult.

Social experiences can in turn provide sensory stimulation that will affect the endocrine status of an individual—sometimes to a large extent. Martha McClintock, at the University of Chicago, discovered that females who live together tend to have synchronized cycles of ovarian hormone production. She has already identified odors as the synchronizing stimuli in rats and is testing to see if the olfactory sense also mediates synchrony in human females. Gisela Epple and Yair Katz, at the Monell Chemical Senses Center in Philadelphia, have evidence that ovarian cycles and estradiol levels are suppressed in young, adult female tamarin monkeys that live in family groups. The stimuli that cause this suppression are thought to emanate from dominant females in the family group.

Not only can social stimulation synchronize and suppress hormone production, it can also increase hormone levels. In order for pregnancy to be successful, many ovarian and pituitary hormones must



Hormones and behavior. A major recent finding is that environmental stimulation affects hormone production and hormones in turn influence behavior long before that behavior is shown. Recent animal experiments in this area may yield important clues to human behavior as well. Examples: Scientists at the Monell Chemical Senses Center in Philadelphia think that among tamarin monkeys living in family groups (left), the behavior of dominant females may suppress the sexual development of younger females. Second, research at Cornell University shows that the developing brain of female quail (top right) must be exposed to the hormone estradiol. Otherwise they develop male or neutral sexual tendencies in adulthood. Finally, work at the University of Massachusetts shows that mother rats (bottom right) treat their newborn pups differently. Apparently the mother responds to the effects of the higher levels of testosterone in males.

interact to ensure implantation of an embryo. Donald Dewsbury at the University of Florida studies females of numerous mammalian species in which sensory stimulation during mating plays an important role in the release of these hormones.

In males also, social interactions can lead to changed hormone levels. For example, there is more testosterone in the blood of male monkeys that have engaged in aggression or copulation that in those that have not. These findings came from the laboratories of James Herndon and Adrian Perachio at Emory University, as well as that of Gisela Epple in Philadelphia. Do these elevated hormone levels increase future aggression or improve mating success? This is an intriguing question, one of many yet to be answered in this rapidly developing field of behavioral endocrinology.

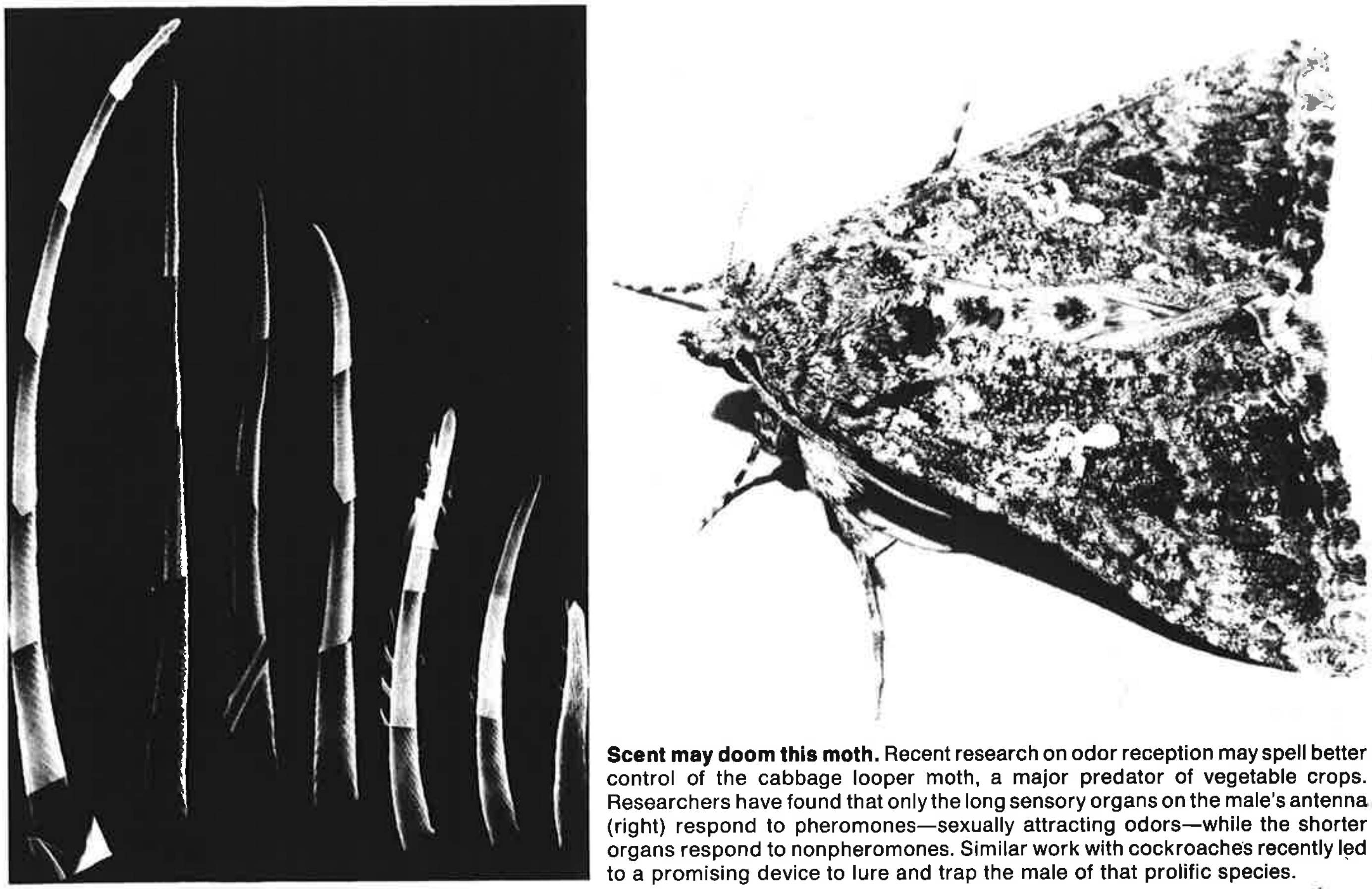
Chemosensory Research

The chemical senses—taste and smell—are relatively poorly understood compared to vision and audition, but they play an important role in many aspects of brain function and behavior. Several years ago NSF helped develop the Association for Chemoreception Sciences, which has aided the exchange of information among diverse chemosensory researchers. It has also helped identify promising developments and accelerate progress in the chemical senses.

Several basic chemosensory research efforts supported by NSF have been especially influential. For example, in 1976 Gordon Shepherd at Yale University began a study of the olfactory system, using a new technique that involved the introduction of a radioactive tracer. The project demonstrated an easy-to-use, sensitive, and non-invasive monitor of sensory-related neural activity in the awake, behaving animal.

It was quickly apparent that this approach provided a tool that was useful not only for research on olfactory organization but also for clinical problems. Extensions of this autoradiographic approach in animals have been important in diagnosing human brain function and disease. The continuing development and exploitation of this methodology as a clinical technique is now sponsored by other agencies, but early NSF support of a basic chemosensory research project played a crucial role in its development.

Similarly, in 1975 NSF supported a basic chemosensory-behavioral project to understand how simple animals communicate by pheromones. William Bell at the Uni-



Scent may doom this moth. Recent research on odor reception may spell better control of the cabbage looper moth, a major predator of vegetable crops. Researchers have found that only the long sensory organs on the male's antenna (right) respond to pheromones—sexually attracting odors—while the shorter organs respond to nonpheromones. Similar work with cockroaches recently led to a promising device to lure and trap the male of that prolific species.

versity of Kansas studied how the male cockroach orients himself to the female pheromone. He found that males attracted by a pheromone could rapidly cover an extraordinary distance and precisely locate the source of the odor emitted by the female. Subsequently, working with industry, the investigator has developed an insecticide trap that uses the sex pheromone to bait the roaches. This research, which began as a basic study into the chemosensory communication system of a simple animal, has led to a safe, species-targeted technology that can efficiently reduce populations of a common and prolific pest.

A final illustration is an ongoing project, by Robert O'Connell at the Worcester Foundation for Experimental Biology, to understand the mechanisms of odor reception. O'Connell is studying the cabbage looper moth, a major vegetable crop predator, by correlating the structure of sensilla (simple sensory organs) on the antenna of the male moth with the electrical responses of receptor nerves to various chemical stimuli.

The moth's antenna has both long, annulated (ringed) sensilla and shorter, smooth-surfaced ones. The long organs respond only to a sex-attractant pheromone, while the shorter sensilla respond to various nonpheromone compounds. Discovery of this intriguing receptor specificity for a sex-attractant pheromone is giving scientists insight into the mechanisms underlying chemoreceptor transduction. It may ultimately provide a biological basis for more effective control of this and other destructive moth species.

Cross-Linguistic Studies in First-Language Acquisition

After concentrating for almost two decades on how children acquire the English language, American scientists have in the past few years begun extending the scope of their research to children learning other languages. Their approach—to determine what is general about the process and what is specific to the language being learned—is yielding important results.

Charles Ferguson and Dorothy Huntington at Stanford University have compared the acquisition of phonology (speech sounds) in English, Spanish, and Cantonese. They focused their attention on the development of one phonological feature: the contrast between "voiceless" sounds such as /p/, /t/, and "voiced" sounds such as /b/, /d/. Their results show that the first stages of acquiring this feature are common to all children regardless of the language being acquired, but the speed of development depends in predictable ways on the specific language.

A particularly significant finding was that children learning English go through a period when they make a systematic distinction—detectable by laboratory instruments but not by adult ears—between voiced and voiceless sounds. This is important because it means that although there is no way for the adults around the children to reinforce it, this bit of learning is taking place anyway.

George Allen at Purdue University has examined the development of speech rhythm in a number of European languages and has highlighted similarities and differences in the developmental course followed by children learning them. His findings on the development of speech rhythm confirm what researchers have learned about other linguistic features—that part of learning consists of "forgetting." In other words, children at early stages of language acquisition display certain abilities that disappear as they get older because they are not part of the language they are acquiring.

Allen has gone beyond other researchers in being the first to pinpoint in time this adaptation process for a particular feature. He finds that French children, at about the beginning of their sixth year, become unable to hear a regular type of stress difference, which they were able to detect six months previously, because it represents a kind of pattern that does not occur in French.

Charles Osgood at the University of Illinois, in collaboration with a network of researchers in a dozen countries, is studying the way children learn to package and organize the semantic content of what they want to say into syntactic forms. One of his research methods is showing children brief films of simple actions involving people and asking them to describe what they saw. Osgood and his collaborators have found that there is a cognitively natural ordering of parts of a sentence that children will follow in the earlier stages of acquisition, regardless of the patterns prescribed by the language they are acquiring. Only with further development does their language begin to conform to the patterns of the adults around them.

Dan Slobin at the University of California, Berkeley, is formulating a set of "operating principles" that appear to guide a child in the process of acquisition, whatever language is involved. For example, it seems to be universally the case that postverbal and postnominal markers are acquired earlier than preverbal and prenominal markers. This suggests that the child uses an operating principle that might be phrased as "pay attention to the ends of words."

These and other cross-linguistic studies are contributing to our rapidly growing knowledge about aspects of language acquisition that are universal and those that are specific to a given language. What is somewhat surprising so far is the broad nature and extent of universal features.

Earliest Agriculture in Egypt

In 1978, following accepted archaeological procedure, Fred Wendorf at Southern Methodist University and his colleagues dug a trench into the side of a sand dune in the Wadi Kubbaniya. This dried river bed is located in the Aswan province of southern Egypt. Most of the evidence recovered there was unexceptional and tended to confirm what archaeologists had already suspected: that about 16,000 to 18,000 years ago small groups of hunters and gatherers lived along the Nile and its tributaries and maintained a seasonally mobile way of life.

Because these people constructed no permanent dwellings and moved as the seasons changed, their presence was marked mainly by thin scatters of charcoal, late Paleolithic stone tools, and bones. At the Wadi Kubbaniya site, Wendorf and his team recovered the predictable remains of

Earliest agriculture. Archaeological excavation in Southern Egypt has given the earliest known evidence of plant domestication. An international research team found fragmentary remains of barley and wheat; with radiocarbon techniques they were able to date them at 17 to 18,000 years ago.

Nile catfish, hartebeests, gazelles, and wild cattle, as well as migrant ducks and geese (which indicate the site was occupied during the winter months).

But the team also performed some non-standard archaeological procedures. They screened the excavated sand through a series of graded sieves down to 0.9-mm mesh size. What was captured in these screens promises to revolutionize anthropological understanding of the origin of domestic plants and the development of complex human societies.

Until the Wadi Kubbaniya excavations, the earliest evidence for plant domestication came from the Near East, well to the north and east of Egypt, and placed this event at approximately 11,000 years ago. Although the causes for this Neolithic Revolution remain unclear, most anthropologists would link this most fundamental change in human subsistence to greater population density (which is evident in the archaeological record). And they would assume that this Neolithic Revolution was in turn a major factor that led to the later rise of urban civilization. In light of new Egyptian evidence, these ideas must now be reconsidered.

In a level dated by radiocarbon to between 17,000 and 18,000 years ago, the Wendorf team recovered fragmentary remains of both barley and einkorn wheat. While it has not been conclusively established that these grains were in fact domesticated, the Wadi Kubbaniya falls well outside the established geographic range of wild relatives of the wheat and barley. Moreover, it seems highly improbable that either species could have survived without human intervention.

Analysis of the barley sample is based on a series of scanning electron microphotographs. In the Middle East, wild and domestic barley have the same cytogenetic stock, and fertile hybrids occur. Grains overlap in size, and by this criterion alone it is extremely difficult to distinguish between the two forms. The SEM photographs, however, revealed what apparently is an early stage of domestication. The one complete barley spikelet from the 1978 excavation showed a smooth base, characteristic of wild forms, but a prominent attachment on the next node of the rachis, which is a departure from the wild type.

In a later excavation, in 1981, the team not only collected additional grain samples but also recovered remains of chickpeas, lentils, and date palm.

What is important is not only the unexpectedly early date and location of these remains, but also the effect—or lack of apparent effect—of this Neolithic Revolution on these early Egyptians. Although such data are difficult to interpret, the archaeological evidence indicates no population pressure before or during this period, and it certainly reveals no major change of lifestyle following the introduction of these domesticates. For at least another 5,000 years these southern Nile populations continued to live in small, highly mobile seasonal groups, and cultivation evidently played a minor role in their overall way of life. These data are causing anthropologists to reconsider what led to this most fundamental change in a human way of life.

The Wadi Kubbaniya is a cooperative venture that brings together archaeologists, geologists, botanists, and paleontologists not only from U.S. institutions but also from Egypt, Poland, and Belgium. It is a model for the way the most productive archaeological research in foreign countries is now done.

Social and Economic Sciences

Despite the perception that human behavior is individualistic, volatile, and changeable, patterns do exist. They emerge not to create a social science but to sustain and extend all that is human. In political, economic, and social matters, a wide range of behaviors is possible. The challenge is to discover which acts really occur, with what frequency, and under what conditions. Understanding these patterns can influence the way society functions; rules and laws that affect our lives often come from this knowledge. In social science, as in the physical and biological sciences, there is excitement in discovering the source of patterns, how they emerge, what forms they take, the links between them, how the patterns break, and how they change.

Human social behavior does not yield easily to scientific probes. However, over time and with increasingly sophisticated sets of methodological tools, the substance of social science is maturing. Social scientists invent new ways to collect, organize, and test data from the real world. Sample surveys, content analysis, case studies, computer simulation, panel studies, mathematical models, cliometrics or the sampling of historical data, multivariate analysis, and linear programing are just a few examples of the tools available.

Use of the computer as a tool for social science research has increased significantly in all disciplines, penetrating even scholarly efforts in the history and philosophy of science. With the computer, social scientists create and analyze large data collections. In political science, computer simulation of game strategies makes it possible to analyze macro-scale interactions among people. In geography, computer programs are used to determine optimal locations for many types of facilities. In the field of law, a computer-assisted procedure breaks down complex symbolic structures of logic so that the inference value of evidence can be assessed.

The development of new analytical concepts also advances inquiry. Demographic accounting is a powerful tool to develop consistent data bases on social change. New exploratory methods, together with regression diagnostics, enable researchers to focus on aspects of research where judgment and detailed knowledge are likely to contribute most to the the analysis. Advances in network analysis link its micro and macro levels.

Methodological advances are also occurring in survey research, improving our ability to deal with missing data and the reliability of subjective survey measures. The need for coordinated, systematic research to improve subjective measurement increases with the growth of the survey industry; the data gathered join a wide variety of commercial, governmental, and scholarly activities.

Linking Micro and Macro Levels of Analysis

Recent NSF-supported research has made significant contributions to our ability to analyze and explain how society combines individual choices and actions into macro-level social organizations. This research focuses on formal organizations and on social networks—the formal and informal structures that unite individuals as a society. The research combines theoretical and methodological advances in analyzing these topics:

- Personnel transitions in private and public-sector organizations.
- The creation and maintenance of markets.
- Policy implementation in federal agencies.
- Corporate philanthropy.
- Activities of nonprofit organizations.
- Decision making by political and other leaders.

For example, Shelby Stewman at Carnegie-Mellon University and John Padgett at Harvard have shown how the impact of decisions made by employers and policy makers is affected by the structure (size, turnover, etc.) of their organizations. These findings show precisely how to predict the effects of policy decisions. Stewman finds that a firm's total labor costs (both dollar and turnover costs) are greater for lateral recruitment than for a program of internal promotions. Padgett indicates that often the most effective strategy for chief executives is to delegate tasks and thus greatly reduce their direct role in many decisions.

Edward Laumann at the University of Chicago, Peter Marsden at the University of North Carolina at Chapel Hill, Joseph Galaskiewicz at the University of Minnesota, and others have shown how the economic and social structure of a community, combined with the activity of community elites, affects political outcomes. Their use of "smallest-space analysis" describes a complex and politically important pattern of social relationships.

Block modeling, as developed by Harrison White at Harvard, Scott Boorman at Yale, and others provides a new methodological tool for the analysis of complex social structures. The method makes it possible to describe how several different kinds of relationships among people or organizations—for example, student-teacher and colleague-colleague or borrower-lender and buyer-seller—operate to create the social structures that sustain research groups, markets, and networks of philanthropists and recipients. These methods now permit the identification of potentially redundant structures in organizations and social groupings.

Dealing with the Missing Data Problem

The sample survey has become the main way to produce detailed knowledge about the characteristics and behavior of large populations. A substantial part of the federal statistical system relies on this method. This includes the decennial census and other data on health, education, agriculture, commerce, and labor. The marketing practices of business and industry and much of academic social science research also depend on the sample survey. However, there is a serious problem in the interpretation of results. Surveys typically fail to get information—or get only partial information—from some of the people designated to be in the sample of respondents. The current trend toward lower response rates in surveys of all kinds, along with the rising costs of achieving reasonable response rates, has increased concerns about the problem of missing data.

At this writing, a panel of experts set up by the National Academy of Sciences is finishing a study of incomplete survey data. Its aim is to look closely at old methods and recommend new ways to plan, analyze, and report surveys so as to minimize the error and bias introduced when some data are missing. The key problem is that nonrespondents can differ from respondents in a variety of ways. The loss of data has the effect of decreasing sample size, which in turn increases the variance and changes the distribution of the sample.

The statistical methods for dealing with missing data focus on both the biases and the sampling error resulting from incomplete data collection. Of course, the preferred method for dealing with nonresponse is to reduce the frequency of missing data in the data-collection process. Even there, care must be taken to ensure that the reductions are not so distributed that the remaining missing data cause even larger biases than would occur otherwise. Still, even after using cost-effective procedures to reduce nonresponse, some bias remains—often at undesirably high rates. Researchers must then use statistical techniques such as these:

- Increasing the weights applied to respondents' data to compensate for the reduction in sample size.
- Poststratifying the population and sample—i.e., defining strata not used in the sample design. This is done with an eye toward putting respondents into groups that are deemed to be relatively homogeneous. Then, when each poststratum's returns are weighted up to population totals, the bias of nonresponse is reduced.
- Imputation (filling in the blanks with assigned responses). There are many varieties of imputation. Among them are duplication of responses for individuals having similar characteristics in the same survey, getting or estimating missing items from an available record or a past survey return for the nonrespondent, or estimating missing values on the basis of regression functions calculated for responding individuals in the same or other surveys.
- Defining a joint distribution of the characteristics of all individuals in the population ("superpopulation" distribution) and predicting missing data—using the distribution and information provided by respondents. Estimates of population characteristics can then be obtained.

A report to be issued by the National Academy of Sciences guides use of these and other techniques and provides ways to measure variability that reflect both sampling error and nonresponse. The report is expected to promote use of appropriate methods to deal with incomplete data. It will make surveys an even more useful research tool and a better guide in decision making.

Improving Survey Measurement of Subjective Phenomena

Attitude surveys, opinion polls, and other measures of subjective phenomena have become a ubiquitous part of life in the United States and in many other countries. Commercial, government, and academic survey organizations in this country do more than 20 million survey interviews a year; measurements made in such surveys are routinely cited in private and public decision making. They have also become an important source of data for social science research.

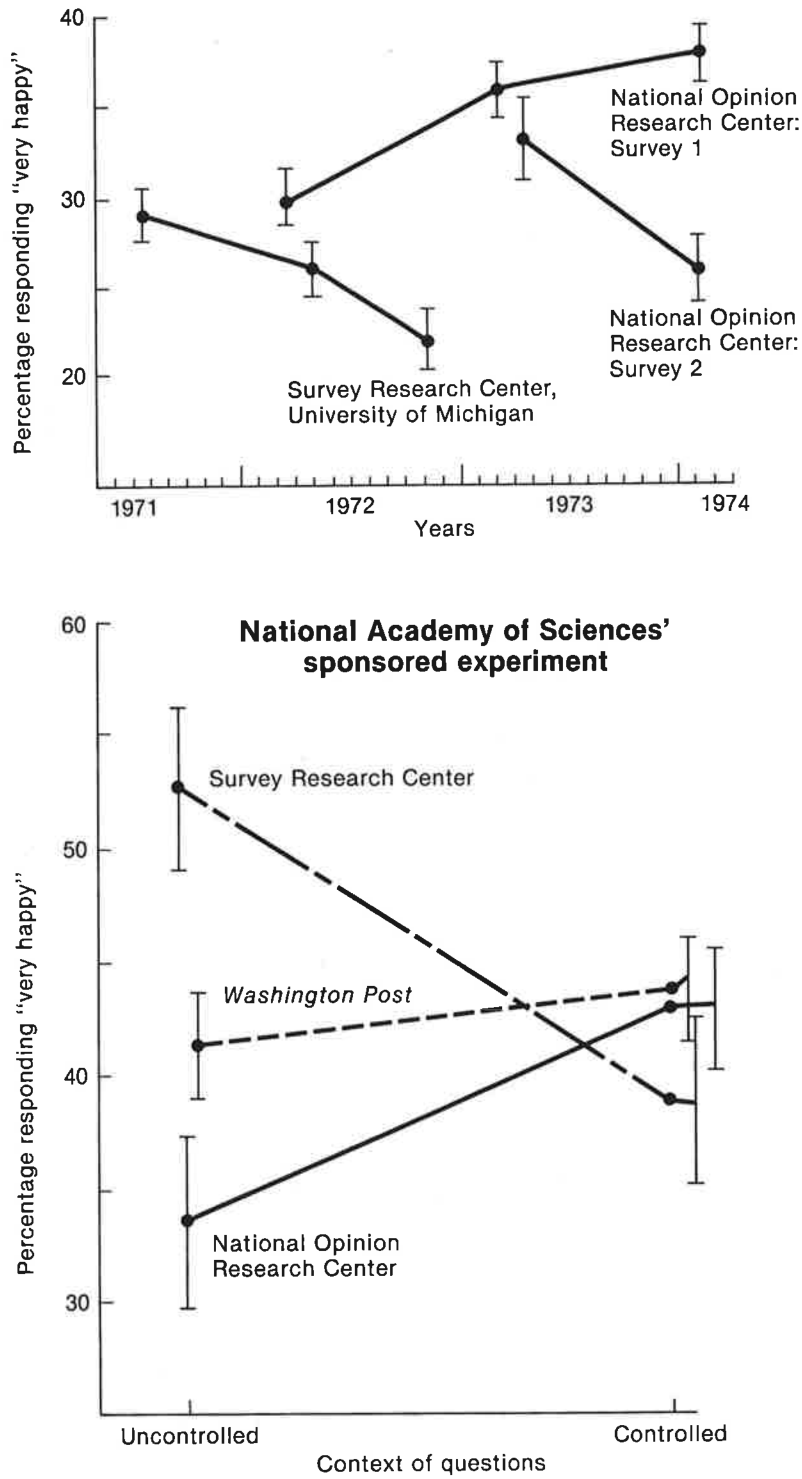
Despite the widespread use of such measurements, the origin and magnitude of the errors (other than in sampling) that commonly affect them are not well understood. Hence the control of these errors is often a most difficult task. In December 1979 a panel of social scientists and statisticians was appointed by the National Academy of Sciences to review the use, reliability, and validity of poll and survey measurements of subjective phenomena.

During 1980-81 the panel prepared a detailed technical review of the use and reliability of subjective survey measures and made a number of recommendations for improving the collection, interpretation, and presentation of such information.

One set of problems addressed by the panel involves observed discrepancies in survey measurements that are allegedly equivalent. An example of this involves three survey programs that asked respondents to assess their level of happiness. There the panel did a series of experiments. It was hypothesized that the context created by the questions that preceded the general happiness question was responsible for observed variations in the happiness measurements. The panel's experiments confirmed that hypothesis. They showed that it is possible to obtain quite consistent survey measurements if the context is controlled; however, when the survey organizations varied the questions that preceded the general happiness question, the results were skewed.

This demonstrated drawback is common to all empirical sciences. For example, recent reviews of measurements in the physical sciences by J. Stuart Hunter at Princeton University and David Lide at the National Bureau of Standards indicate that analytic measurements in other fields often show analogous types of variability.

Commenting on published measurements of the thermal conductivity of copper made by different laboratories, Hunter observed that "Although each analyst measured a physical quality that did not vary with



Note: Error bars demark approximately ± 1 standard error around sample estimates.

Questions: "Taken all together, how would you say things are these days — would you say that you are very happy, pretty happy, or not too happy?" (National Opinion Research Center)

"Taking all things together, how would you say things are these days — would you say you're very happy, pretty happy, or not too happy these days?" (Survey Research Center)

All surveys used the National Opinion Research Center wording in the National Academy of Sciences' sponsored experiment.

Survey discrepancies. Measurements of subjective phenomena, such as those shown at the top for self-reported "happiness," may sometimes show notable differences. To investigate this common problem in social science research, a National Academy of Sciences panel sponsored a series of experiments based on another set of surveys asking for the same self-evaluation of happiness. The panel found that the context created by questions asked before the one on general happiness induced measurement variations. Consistent results were obtained when the context was controlled, as seen at the bottom.

location or time, it is clear that a remarkable variability attended such measurements." He also noted that when 100 cooperating laboratories evaluated the amount of lead present in identical samples of blood, the estimates ranged from 33 to 55 units for a sample with a putative concentration of 41 units. Variations in measurements of social science phenomena compare favorably with these results from the physical sciences.

Programs of interlaboratory research and the coordination and standardization of measurement procedures are common in many fields in the natural sciences. Measurements made with standard samples should, in principle, yield the same result. However, results often vary. Evaluation of the variability of measurements provides a better understanding of the error structure of basic data. Such evaluation also encourages routine monitoring of the quality of those measurements, and it may permit the identification of robust or rugged analytic procedures (i.e., those that produce low variation in measurements across laboratories, trials, and/or experimenters).

The NAS panel has recommended that survey organizations (and those who support and use the measurements they provide) should consider developing analogous procedures for coordinated measurement to improve both the practice of survey measurement and understanding of the social and statistical aspects of the resulting data.

In addition to its work in this area, the NAS panel has made a number of other recommendations that should stimulate better survey practices. In the winter of 1981-82, the Academy plans to convene a conference of producers, sponsors, and users of subjective survey data. That group will work on carrying out the panel's recommendations.

Information Science and Technology

Serious scientific inquiry about information phenomena deals with the structure of information, its storage, movement, manipulation, retrieval, recoding, and interpretation. Information scientists study how information can be represented and used in humans, in machines, in the contacts between them, and in the abstract.

Recent progress in information technology has stimulated research on certain old problems and opened new areas of study as well. Moreover, for the first time this technology is giving researchers the chance to collect and analyze large quantities of observational and experimental results, the foundation for future theories and their application. In effect, research in information science is entering a new, broadly based phase. Today we can better recognize common problems in the different fields of science and integrate possible solutions to those problems.

Advances in microelectronics and computer technology—and the growing perception of the importance of information in economic and social functioning—have raised new questions for scientific analysis. The flexibility of advanced information technologies has created challenges for the organization and structuring of information and the design of information-processing systems and the functions they serve.

The power of information-processing machines has increased and their costs have declined, to the point where machines with "intelligence" (information-transforming capacity) are spreading throughout society. Concomitantly, advanced societies are said to be in a state of transition from economic systems based on industrial production to those based on information transfer. In such economies a major imperative is to increase the productivity of knowledge workers by augmenting the human intellect, using information-intensive machines. This contrasts with previous technologies, which supplemented and replaced human muscle power and resulted in the productivity gains seen in the first three-quarters of this century.

Scientific research is a typical example of knowledge work. Information systems of the future will enable a scientist to conduct a meaningful "dialog" with a body of recorded knowledge. Such systems could eventually mean new research techniques based on the computer as a tool. They could help scientists develop new ideas and hypotheses, retrieve facts and pertinent literature, and, coupled with communication technologies, help spread ideas and feed back responses from the scientific community. Thus, future scientific information systems will combine the elements of information retrieval, data reduction and analysis, and communication.

Many of the right components exist, but the fundamental information-transfer processes that will enable development of these systems are as yet poorly understood. Information science works to provide the knowledge base to make such systems a reality.

To accomplish this objective, research is under way across a broad range of distinct but related problem areas. Research on the structure of information is one of the most important. Information can be presented in a variety of ways that do not essentially differ. For instance, a statement of fact can be conveyed in any one of the hundreds of natural languages currently in use, via print or braille or speech waveforms. Some information, then, is independent of the form in which it is presented; this shows how central research on the structure of information is to the field of information science. Such research is important, for example, in developing more effective information collection and access systems; in understanding the connection between statistical theories and structural properties of information; in the representational structure of information patterns in text, image, and numerical archives; and in the relationship between form and content in language.

Correlation of Language Structure with Information

One possible way to understand the structural properties of information is to examine the structural properties of the language carrying the information. Zellig Harris at the University of Pennsylvania took this approach in extending earlier findings, which had shown that each sentence of a language is derived, in a regular and computable way, from a series of more simple statements, and that these simple statements (reductions) contain all the information that is in the sentence. The simple statements cut across language lines, and the information properties represented seem to be the same for a sentence (or a scientific article) in English and its translation in French.

These previous findings from research in computational linguistics made possible Harris's new research on structure and information properties. In particular, he investigated the vocabulary for expressing relations, namely prepositions. He found that prepositions play two fundamental roles: some provide space and time-order meanings in a sentence (e.g., *up* in *He looked up*), and others connect a sentence to a noun (e.g., *on* in *He sat on a chair*). From these fundamental roles of prepositions, more complex ones evolve. This research eventually will permit automated information systems to extract complex relational meanings from natural language representations.

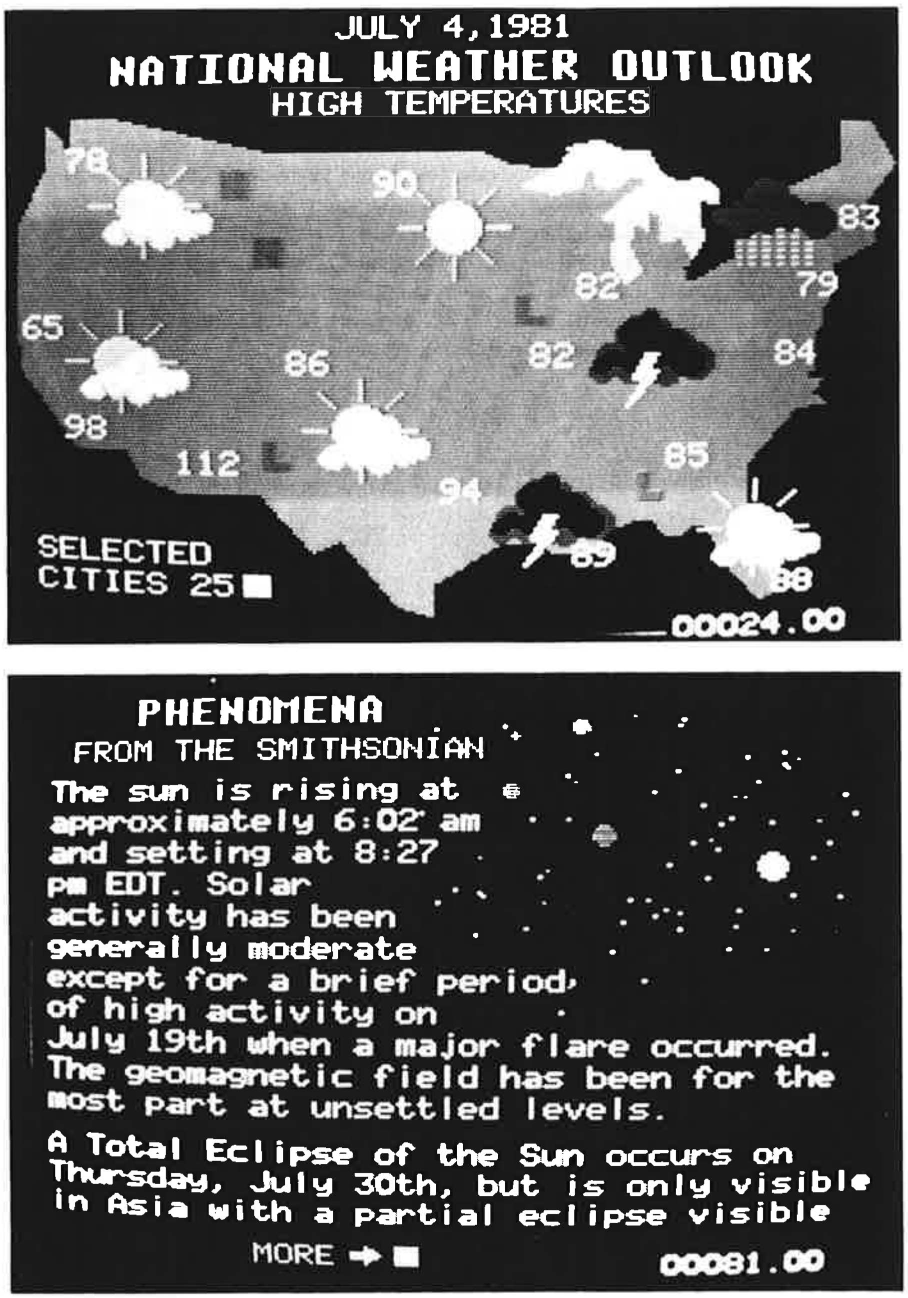
The importance of this work for a theory of information lies in the fact that the reductions do not alter the objective and substantive information in a sentence. The reductions thus lead us to define a particular kind of meaning. It is not the same as the whole of "meaning" in the informal sense but is the objective information preserved under reduction. This information is the same in a base sentence and in its various reduced forms. Information reduced in this fashion, without subjective expectations or stylistic implications, is the "public" information of a sentence, which would be desired in any fact-processing system and particularly in a computer treatment of scientific information.

From the point of view of applications, the significant finding here is that in each text it is possible to reduce the successive sentences into a base form algorithmically. Eventually a computer can manipulate the essential meaning of information in the original texts.

As we develop the knowledge base for better information-handling and transfer systems through research in information science and technology, we must also be aware of the possible impacts of these new developments. That insight will enable more rational decisions on applying the new technology.

Teletext for Public Telecommunications Systems

Scientists who study the impacts of information use methods from the traditional economic, social, and behavioral sciences. One example of a current study involves teletext, an inexpensive, flexible means to manipulate, transmit, and access print and graphic information on an unused portion of the normal broadcast television signal. In application, it blurs traditional distinctions between print and broadcast media for both providers and users. Teletext combines important qualities of mass communication and individual information-retrieval systems.



Teletext. The first operating system of its kind in the United States (and the only one used for scientific research), this inexpensive and flexible way to use telecommunications is an experiment run by New York University and a public television station in Washington, D.C. Teletext is a means to access print and graphic information from a computer base and transmit it on an unused part of a normal broadcast television signal. Among those supplying information to the main storage computer are newspapers and periodicals, consumer groups, and federal agencies. Here viewers see data from the National Weather Service and Smithsonian Institution on their television screens.

From the user's viewpoint, broadcast teletext provides a way to access text and graphic information from a computer data base. Using a keyboard, the user selects information from an index display on a home television set. Simple, successive selections are made to delve deeply into the data base for information such as news, sports, weather, job listings, educational materials, games, airline schedules, and anything else that information providers enter into the main storage computer. The technology is relatively inexpensive, easy to use, and within the capability of most local TV stations.

The teletext experiment is in Washington, D.C. It is conducted by New York University with the cooperation of WETA, a Washington-area public broadcasting station. It is the first operational teletext system in the U.S. and the only one used for systematic science research. Information providers include the *Washington Post*, the *New York Daily News*, the Departments of Labor and Education, the Internal Revenue Service, the National Weather Service, the D.C. city government, *Reader's Digest*, and Consumer Checkbook, a local service organization. More are being included as experience is gained with organizing, formating, and displaying information in ways that optimize system use.

Initially 60 television receivers have been deployed in a systematic sample of residential and public locations. The research design calls for moving these to other locations, and, if warranted, expanding the sample considerably.

Research in this project focuses on issues such as these:

- Psychological factors in effective formats and graphics, user acceptance, and impacts on information acquisition and use.
- Management of complex public information systems.
- Implementation costs.
- Technical questions as to tradeoffs among access time, the size and depth of the data base, and programing techniques to optimize the new medium.

Much of the research is aimed at producing fundamental knowledge about new electronic media. This knowledge should also be a useful base for sorting out issues on the relationship between electronic and print-based information industries and the role of the broadcast industry in providing text services.

Astronomical, Atmospheric, Earth, and Ocean Sciences

4

These programs support research that increases our knowledge of the natural environment on earth and in space, and of various effects of human activity that interact with this environment. Overall objectives are to obtain new knowledge encompassing the broadest possible scope of natural phenomena, both on earth and in space. Specific goals are as follows:

- To increase our understanding of the physical nature of the universe.
- To advance knowledge of the behavior of the earth's atmosphere.
- To provide further insights into the physical and chemical makeup of the earth and its geologic history.
- To improve knowledge of the composition of the world's oceans, their dynamic properties, the sea floor underlying them, and the creatures they nurture.
- To advance knowledge of natural phenomena and processes in the polar regions.

The form of support for this research may be grants to universities for individual investigators, grants to groups working together on a major project, or support of national research centers and facilities.

NSF's astronomy programs are the primary source of support for U.S. ground-based astronomy. In addition to research grants to academic institutions, support is provided for five national centers that operate some of the largest and most advanced optical and radio telescopes in the world. Scientists compete for free observing time at the national observatories; this enables astronomers at universities without research telescopes to undertake major research programs.

Significant recent events in astronomy include the use of new optical and radio telescopes of large aperture and new types of instruments for observing in the x-ray, ultraviolet, and infrared wavelengths. These new tools have provided details of a surprisingly active cosmos filled with stars that are forming out of interstellar gas and dust; losing mass back to space or companion stars; or dying as supernovae, black holes, or white dwarfs.

Other recent developments:

- Increasingly sensitive electronic light detectors and similar instruments have doubled the extent of the observable universe over the past two decades. Optical astronomers at the Kitt Peak National Observatory in Arizona and the University of California's Lick Observatory near Santa Cruz have identified galaxies 10 billion light years distant. By doing so, they have possibly peered far enough back in time to witness significant cosmic evolutionary effects.
- The simultaneous use of widely separated telescopes has enabled radio astronomers at the California Institute of Technology to record puzzling motions in quasars that would appear to exceed the speed of light.
- Studies of binary neutron stars further confirm Einstein's general theory of relativity.

In the atmospheric sciences, the Foundation supports research through grants to U.S. academic institutions and contracts for the operation of two major centers: the National Center for Atmospheric Research in Boulder, Colorado, and the National Scientific Balloon Facility in Palestine, Texas. Research objectives in the atmospheric sciences involve more accurate and longer-range prediction of future states of the atmosphere, understanding of the chemistry of the atmosphere and fluctuations in chemical cycles, and learning about the physical processes that may in time allow effective weather modification activities. Ultimately this research can help solve or alleviate atmospheric problems, including those associated with pollution. In addition, information on the origin of drought

Table 4
Astronomical, Atmospheric, Earth, and Ocean Sciences*
Fiscal Year 1979, 1980, and 1981

(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Astronomy	248	$ 16.34	244	$ 17.66	225	$ 19.40
Atmospheric Sciences	475	31.98	433	34.48	486	37.62
Earth Sciences	503	24.92	491	25.48	516	27.86
Ocean Drilling	0	11.62	0	19.47	20	21.99
Ocean Sciences	662	62.39	624	66.31	618	74.97
U.S. Antarctic Research	140	51.09	126	55.84	148	67.45
Arctic Research	87	5.97	67	5.82	66	5.82
Total	**2,115**	**$204.31**	**1,985**	**$225.06**	**2,079**	**$255.11**

*Excludes National Research Centers (See table 5)

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

and severe storms such as tornadoes and hailstorms is critical to our well-being.

In 1981 the atmospheric sciences put special emphasis on these areas:

- Particle processes as they determine energy, chemical, and radiative balances in the upper atmosphere, ionosphere, and magnetosphere.
- Radar measurements of the global dynamics and composition of the atmosphere up to 150 kilometers.
- Mesoscale (regions 10 to 1,000 kilometers in size) meteorology that encompasses all local weather phenomena, such as cloud formation.
- Numerical climate modeling for diagnostic studies and applications to societal issues, such as the carbon dioxide increase.

In the field of ocean sciences, there was substantial progress during 1981, not only in basic ocean research but in the application of new technologies and in facility upgrading as well. Advances were made in all major fields supported by the Foundation: biological, chemical, and physical oceanography, and submarine geology and geophysics.

Scientific advances have often closely followed technological developments, as shown by the biological oceanographer's new ability to assess the relative role of microorganisms in the open ocean's food chain. Quantitative determinations of biochemical processes are just becoming possible with the new sampling techniques and analytical equipment. As a result of a detailed experiment to evaluate several experimental sampling devices, chemical oceanographers can now assess the flux of nutrients and other materials in the oceans. A new sea-floor corer is revolutionizing our knowledge of ancient climates and conditions on earth, and new remote sensing buoys and satellites are letting oceanographers study ocean processes on appropriate space and time scales.

The year 1981 also saw the completion, delivery, and dedication of two new NSF-built research vessels. This marked the culmination of more than six years of planning to modernize and upgrade the nation's academic research vessel fleet. The two new vessels replace older and more costly ones and are especially designed for coastal ocean research.

In ocean drilling, work continued on the deep-sea drilling project, carried out by the NSF research vessel *Glomar Challenger*. Several more legs, or cruises, were completed last year, with important findings on land masses and how they separated; the geological history of some ocean bottoms; the use of unmanned observatories in holes drilled on the sea floor; and a new fault zone.

Research across the whole range of earth science disciplines is strongly influenced by new opportunities stemming from the plate-tectonics concept. More understanding of the earth's history and the evolution of life helps us apply basic knowledge to meet human resource needs and cope with environmental problems. The major emphasis is shifting toward multidisciplinary research, particularly evolution of the lithosphere as a component of a dynamic earth.

Current research in the earth sciences deals with key processes of the present and the past. Studies on the uplift of island arcs above subduction zones add to our understanding of ancient collisions that expanded the continental crust and built mountain belts, as well as assessments of modern earthquake hazards. Research on the geochemical dynamics of magmas tells us how molten material from the earth's mantle becomes igneous rock, with associated ore deposits, in the continental and oceanic crusts.

Deployment of a network of low-frequency accelerometers has added greatly to the interpretation of seismic data. This will help us comprehend earthquake mechanisms and regional heterogeneities in the structure of the earth's crust, and it can lead to improvements in tsunami warning systems.

NSF is one of several sources of federal funding for research in the arctic and is solely responsible for funding and managing the U.S. program in the antarctic. In Antarctica, solar observations at the South Pole have provided new information on the sun's interior: the convection layer was found to be far larger than thought, and the chemical makeup of the sun was confirmed as that of a typical star. Siple Station, 800 miles from the South Pole, was the scene of an upper-atmosphere probe using rockets and high-altitude balloons. In the southern ocean, investigators discovered a swarm of krill several square miles in extent—probably the largest school of marine animals ever measured.

In the arctic, an ice core at the bottom of the southeastern Greenland ice sheet—2,037 meters deep—gave information on climate and atmospheric makeup over the last 130,000 years. This was only the third core ever drilled to the bottom of an ice sheet; the others took place in the 1960s.

Table 5
National Research Centers
Fiscal Year 1979, 1980, and 1981

(Dollars in Millions)

	Amount		
	Fiscal Year 1979	Fiscal Year 1980	Fiscal Year 1981
Kitt Peak National Observatory	$ 9.70	$10.50	$11.10
Cerro Tololo National Observatory	4.35	4.83	5.81
National Radio Astronomy Observatory	22.70	17.03	14.79
National Astronomy and Ionosphere Center	4.63	4.99	5.41
Sacramento Peak Observatory	1.50	1.66	1.86
National Center for Atmospheric Research	25.26	26.59	29.23
National Scientific Balloon Facility	1.87	2.20	2.42
Total	**$70.01**	**$67.80**	**$70.62**

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Astronomy

Astronomy is a field of great scope, diversity, and vitality: astronomers apply the principles of physics and chemistry to observe and understand the universe beyond the earth. We now have new optical and radio telescopes of large aperture and new instruments that sample previously inaccessible wavelengths such as x-rays, the ultraviolet, and the infrared. These tools show a surprisingly active cosmos filled with stars forming out of interstellar gas and dust; losing mass back to space or companion stars; or dying as supernovae, black holes, or white dwarfs.

The theoretical explanation of astronomical evolutionary processes has been a major intellectual achievement of the past decade. Supernova explosions not only enrich the interstellar gas with the heavy elements needed to form planets and life, but also seem to provide the impulse for a new generation of stars to be born. In a hierarchy seemingly without end, stars and gas clouds make up galaxies, clusters of galaxies, and superclusters.

Instrumental developments like those of increasingly sensitive electronic light detectors have doubled the extent of the observable universe over the past two decades. Near the horizon of the universe lie the enigmatic quasars; their extreme luminosities indicate highly energetic processes that seem to be related to those occurring in the explosively active nuclei of certain galaxies. All of these phenomena may involve the fall of gaseous material into supermassive black holes, whose presence in galaxies, including our own Milky Way, would explain certain galactic internal motions.

Many sources of x-rays and gamma-rays are also thought to be the products of gas accretion onto neutron stars or black holes. A celestial body called SS 433 appears to be a binary star containing a neutron star or black hole; it exhibits radio-emitting jets that suggest the double radio sources associated with many quasars.

The rapid pace of recent astronomical discoveries has been largely due to the accelerated rate of technological advance. New techniques such as very long baseline radio interferometry and computer picture processing have improved the resolution or clarity of observations by several orders of magnitude.

NSF supports research at more than 140 universities, private and federally owned observatories, and industrial firms through grants and allotments of observing time at the national observatories. Ground-based and theoretical studies of the composition, structure, and evolution of the sun, the solar system, stars, the interstellar medium, and galaxies all receive NSF funding. There is also a program to promote the development of new instrumentation and computational capabilities.

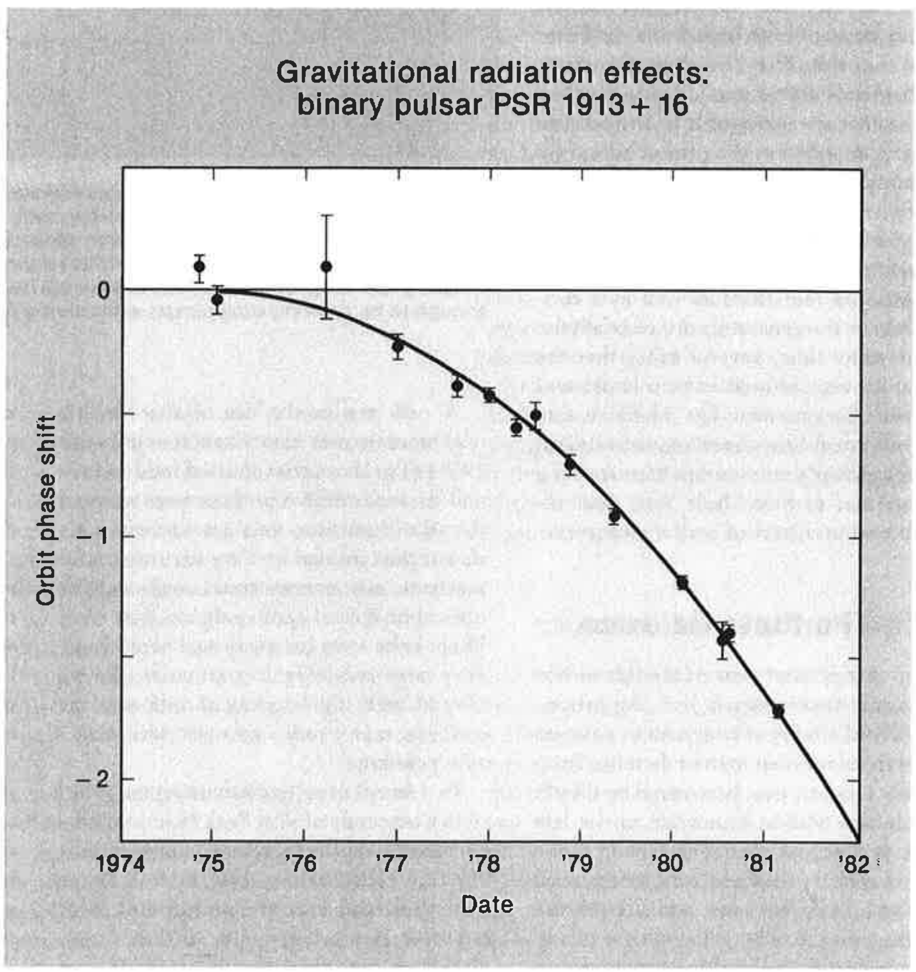
Astronomers throughout the nation have access to telescopes, instruments, and facilities ranking among the largest and most advanced in the world. They can do investigations in optical, infrared, and radio astronomy at these five national astronomy centers supported by NSF:

- The National Astronomy and Ionosphere Center in Puerto Rico.
- Kitt Peak National Observatory in Arizona.
- Cerro Tololo Inter-American Observatory in Chile.
- The National Radio Astronomy Observatory in Charlottesville, Virginia, with observing sites in West Virginia, New Mexico, and Arizona.

Staff at these observatories not only aid visiting astronomers but also carry out their own research activities.

Gravity Waves

Gravitational radiation was predicted decades ago as a consequence of Einstein's general theory of relativity. But the first direct experimental evidence for it was found only in 1978, by Joseph Taylor and Lee Fowler at the University of Massachusetts at Amherst and Peter McCulloch at the University of Tasmania, Australia. They made the discovery after a four-year study of the pulsar PSR 1913+16 with the 305-



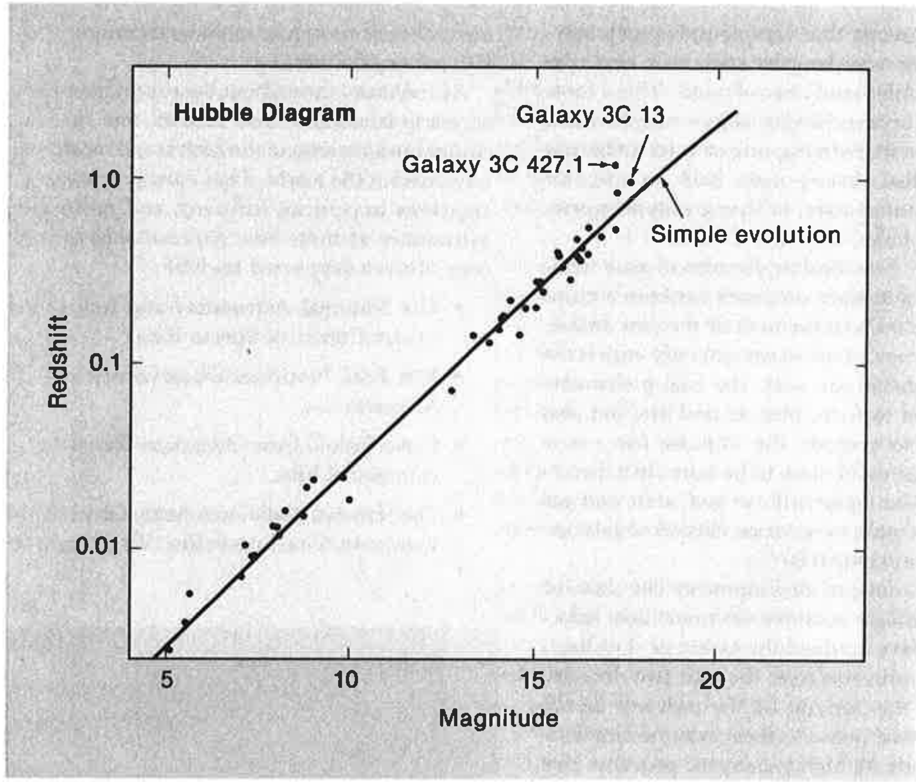
Relativity: further confirmation. The shortening of the orbital period of the binary pulsar PSR 1913+16 is shown here to be in excellent agreement with the curve predicted by general relativity theory on the basis of energy losses due to gravitational radiation. This finding supports the existence of such radiation and confirms the theory of relativity as well. The pulsar under study is the only "double" of the 326 now known: it is orbiting either another pulsar or a black hole.

meter Arecibo radio telescope of the National Astronomy and Ionosphere Center—still the only instrument capable of detecting the faint object.

Discovered in 1974 by the same research group, PSR 1913+16 is also known as the binary pulsar: an eight-hour variation in the spacing of its radio pulses indicates that it is orbiting another massive object, perhaps another pulsar or a black hole. This is the only pulsar of the 326 now known that has been found to be double. According to relativity theory, the emission of gravitational waves slowly extracts energy from the orbit, causing the two objects to move closer together and shortening the orbital period by a predictable amount.

Taylor and Joel Weisberg, at both the University of Massachusetts and Princeton University, extended their observations of the binary pulsar at Arecibo into 1981. Eventually they had enough data to solve for the masses of both bodies and the linear size of the orbit. They found equal masses, both 1.4 times that of our sun. These values and the characteristics of the orbit motion predict a decrease in the orbital period by an amount agreeing even better with relativity theory than before.

Taylor's and Weisberg's result offers compelling evidence for the existence of gravitational radiation, as well as a confirmation of the general theory of relativity. At the same time, several other theories of gravity were shown to be inconsistent with the observations. The available data and theoretical considerations still suggest that the pulsar's companion is probably a neutron star or black hole, both the collapsed end products of stellar evolution.



On the horizon of the universe. This Hubble diagram—which relates a galaxy's distance from the earth to the speed at which it is moving away—shows two radio galaxies whose optical redshifts, or movements away from the observer, are the greatest ever measured. The galaxies can be placed at a record 10 billion light-years from earth. They are also above the line corresponding to a uniform expansion rate for the universe, which means they may be old enough to be showing evolutionary effects on galaxy composition.

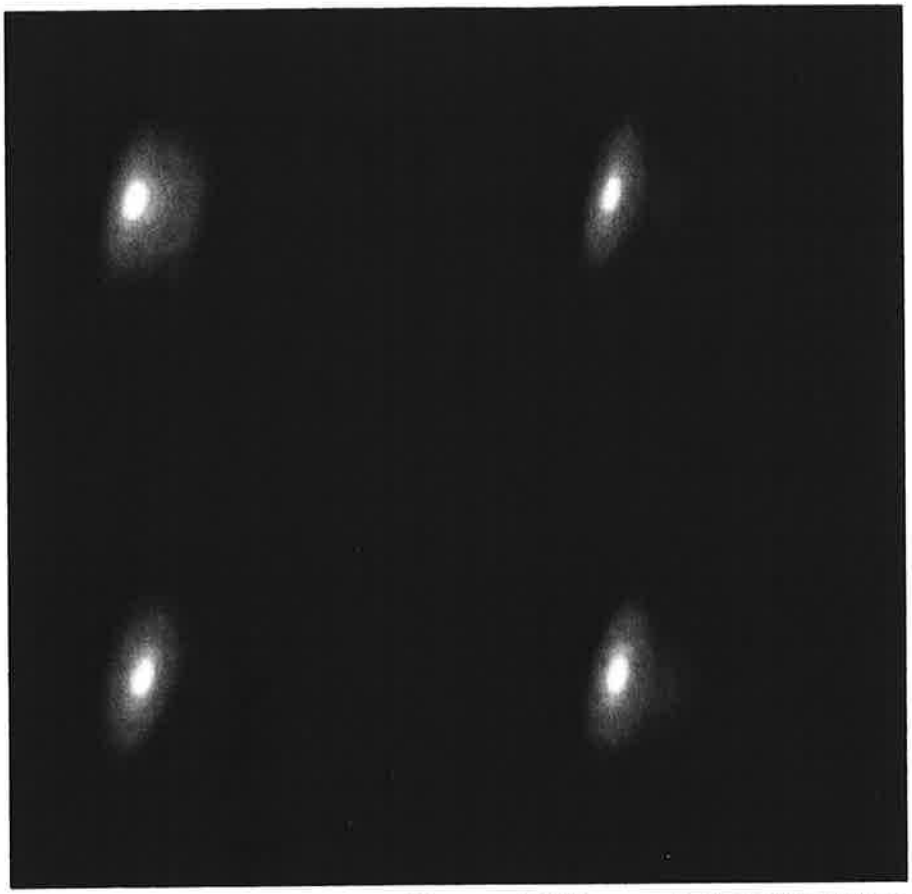
The Furthest Galaxies

One of the most powerful tools of observational cosmology is the proportionality of the velocity at which other galaxies recede from our own to their distance from us. This relation was discovered by Edwin Hubble and Milton Humason in the late 1920s. It is a consequence and proof of the expansion of the universe, which originated some 18 billion years ago, according to the Big Bang theory. The velocity of a galaxy is inferred from the displacement (or Doppler shift) of characteristic lines in its spectrum. A shift toward red wavelengths would mean the object is moving away from the observer.

A new era in the use of the Hubble relation came with identification in the early 1950s of galaxies that emitted radio waves and the realization that these were some of the most luminous galaxies known. This meant that, guided by very accurate radio positions, astronomers could single out the optical images of radio galaxies that were likely to be very far away and hence have very large redshifts. In particular, the 3C (third Cambridge) catalog of radio sources contains many radio galaxies with accurate positions.

In a recent investigation using the four-meter telescope of Kitt Peak National Observatory and the three-meter telescope at the Lick Observatory, Harvey Butcher at Kitt Peak and Hyron Spinrad and John Stauffer at the University of California, Berkeley, measured the redshifts of two galaxies identified with the radio sources 3C 13 and 3C 427.1. The researchers accumulated 40 hours of observation over 3 years with a computerized image-tube spectrum scanner. They found redshifts greater than any measured before, placing the giant galaxies 10 billion light-years from earth, 2 billion light-years further than the most distant galaxy known before.

Because the light from these galaxies required 10 billion years to reach the earth, they are seen as they were 10 billion years ago. Their sighting means that astronomers have now looked more than halfway back to the moment believed to mark the origin of the universe. The galaxies are 10 times as large as our own Milky Way but may be somewhat bluer in color. The latter possibility means that astronomers may have finally peered far enough back in time to witness significant evolutionary effects, since a very young galaxy would be expected to contain many luminous blue stars. If the magnitude, or brightness, of these galaxies can be corrected for this effect, it should be possible to use their positions on the Hubble redshift-magnitude diagram to predict whether the universe



Faster than light? Radio contour maps of the quasar 3C 273 were made at four different times in a recent three-year period. During that time this gaseous knot seems to have moved from 62 to 87 light-years from the quasar—which would indicate a velocity greater than the speed of light. Such "superluminal" motions may be explained by geometric effects. These observations were made through improved techniques of very long baseline interferometry, which helps astronomers see extragalactic objects like the quasar much more clearly than before.

will expand forever or eventually stop and collapse back on itself.

The Quasar 3C 273

The technique of very long baseline interferometry (VLBI) is a fairly recent development. It has enabled radio astronomers to see the detailed structure of emitting objects with a clarity that rivals or exceeds that previously attained only at optical wavelengths. The method involves the comparison of simultaneous observations by two or more widely separated radio telescopes. A wavefront from a radio source generally arrives at two such instruments at different times; combining simultaneous observations results in wave interference that yields precise angular information essential to the accurate determination of position and structure. A resolution of better than one-thousandth of a second of arc has been achieved, corresponding to a separation of light-years in even the most distant galaxies and quasars.

The application of VLBI has resulted in the discovery of rapid expansion in certain extragalactic objects. In four extreme cases (three quasars and one galaxy), this expansion apparently exceeds the speed of light, assuming that the objects are at the great distances implied by their velocity of recession and the expansion of the universe. Actual faster-than-light, or superluminal, motions are contrary to the theory of relativity, so the phenomenon has been interpreted as a relativistic deflection of light emitted from material in rapid motion almost directly toward the observer.

Timothy Pearson and his colleagues at the Owens Valley Radio Observatory of the California Institute of Technology have monitored the quasar 3C 273 for three years. They used four or five antennas in California, Texas, West Virginia, Massachusetts, and West Germany. While previous evidence for superluminal expansion has been limited and uncertain, the observations and refined analysis of this team give the first direct and umambiguous evidence for the phenomenon in any radio source. They observed a luminous knot in 3C 273 moving at a constant apparent velocity 9.6 times as fast as that of light.

The Peculiar Star SS 433

One of the most exotic objects in our galaxy is the radio source SS 433, described in NSF's annual report for 1980. First noted in the 1960s as a star with a peculiar spectrum, the object was later found to be a variable radio and x-ray source. As the second star discovered to be an extended (rather than a point) radio source, SS 433 is located in an expanding gas cloud known as W50, the largest supernova remnant yet found.

The most extraordinary feature of this body was discovered by Bruce Margon (now at the University of Washington) and his colleagues at the University of California, Los Angeles and Santa Cruz. Hydrogen and helium emission lines in the spectrum of SS 433 exhibited Doppler shifts indicating simultaneous velocities of approach and recession. The shifts varied with a period of 164 days and attained a maximum of 50,000 kilometers per second, or 17 percent of the speed of light, 100 times as fast as that ever observed in a stellar object. Other spectral lines showed a small velocity variation with a period of 13.1 days.

The model that most successfully accounts for the bizarre behavior of SS 433 postulates a binary system consisting of a normal star and the vestigial core of a supernova, specifically a neutron star or black hole, orbiting around each other every 13.1 days. Gravitation strips gaseous material from the normal star and spirals it into an accretion disk around the dark companion. When this disk overloads, dense, superheated plasma (ionized gas) is ejected in a tight beam in opposite directions perpendicular to the disk. The gravitational attraction of the normal star causes the disk to precess, or wobble, around the dark companion once every 164 days.

Robert Hjellming and Kenneth Johnston of the National Radio Astronomy Observatory have obtained radio maps of SS 433 with the Very Large Array telescope. The maps fit the three-dimensional corkscrew pattern one would expect for a twin-jet ejection with a precessional period of 164 days and an angle of 20 degrees from the precessional axis. Their observations also signify that the radiation from the jets is nonthermal in character and strongly polarized linearly—as it would be if it were the product of the interaction of electrons moving at relativistic speeds with a magnetic field aligned along the corkscrew. Relativistic time travel effects imply an unforeshortened velocity of 26 percent of the speed of light; this, together with the observed angular motion of the jets, yields a distance for SS 433 of 18,000 light-years from earth.

National Astronomy and Ionosphere Center

NAIC's major observing facility is located near Arecibo, Puerto Rico. The main instrument there is the antenna, at 305 meters in diameter the world's largest radio/radar telescope. NAIC also operates two remote sites, one 11 kilometers north of the observatory, where a 31-meter antenna is located, and the other 17 kilometers north of the main site, home of the High-Frequency Ionospheric Heating (or HF) Facility. NAIC is operated by Cornell University under contract with NSF. The center supports research programs in radio astronomy, planetary radar ranging, and atmospheric sciences.

The past year has seen major improvements in several receiver systems. Most significant was the installation of a dual-channel cryogenic GaAsFET receiver, which has doubled the system sensitivity at the 21-centimeter hydrogen line and greatly increased both the quality and quantity of the hydrogen-line data. It made feasible observations that were not previously possible and quadrupled the telescope's "speed" by reducing the time required for observations. Another improvement in sensitivity came from the installation of dual-channel, 2,380-megahertz maser receivers at the main telescope and the 31-meter antenna.

The center continues to be in great demand by the scientific community, and use of the recently completed HF facility has been particularly heavy and successful. Visitors in 1981 were more than 10 times the annual number in the early 1970s.

Replacement of a central backstay cable that had several broken wires took place in the summer of 1981. The cable is part of the support system for the 660-metric ton, suspended feed structure. The telescope continued in operation during the entire procedure. The old cable will now be subjected to a series of tests to find out whether any of the other main structural cables need to be replaced.

Kitt Peak National Observatory

KPNO is operated under contract with NSF by the Association of Universities for Research in Astronomy, Inc. (AURA), a nonprofit consortium representing 16 universities in the United States. As the nation's major center for optical and infrared astronomy research, KPNO provides U.S. astronomers with access to the large telescopes, auxiliary instrumentation, and support services needed for observational and theoretical research programs in stellar, solar, and planetary astronomy. Its observing facilities atop Kitt Peak, 90 kilometers southwest of Tucson, include 10 stellar and 4 solar telescopes. The observatory's offices and laboratories are in Tucson, Arizona, adjacent to the University of Arizona.

In the past year, KPNO successfully experimented with a sophisticated new observing technique. For five nights in early June, telephone and computer links enabled a University of Michigan astronomer to use the observatory's 2.1-meter reflector to search for distant clusters of galaxies without leaving his office in Ann Arbor. A 30-second delay in the images being presented on the remote television display made operator assistance necessary at Kitt Peak to place the telescope on target. In the future, links by satellite rather than telephone will render this help unnecessary and will permit the expansion of such observing throughout the United States. Still unknown is whether the technique will be cost-effective, but the potential is high for significant savings in travel time and costs, as well as reduced requirements for visitor accommodations on Kitt Peak. This experiment is of special interest in light of the heavy demand on KPNO by visiting astronomers.

Cerro Tololo Inter-American Observatory

CTIO is also operated by AURA under contract with NSF. This observatory's eight optical telescopes are the only ones generally available to U.S. scientists for studying the southern skies. They include a four-meter reflector, the Southern Hemisphere's largest and a twin to the KPNO Mayall telescope. CTIO is headquartered in the coastal town of La Sereña, Chile, approximately 80 kilometers by road from the mountain location of the telescopes. The observatory's location at 30 degrees south latitude and the exceptionally good atmospheric conditions over Cerro Tololo are ideal for the study of such important Southern Hemisphere objects as the Magellanic Clouds and the central regions of our own galaxy.

A major instrumental advance at CTIO during 1981 was the completion of a large SIT (silicon-intensified target) vidicon camera for use with either spectrograph of the four-meter telescope. The project has increased the power of that instrument by a factor of 10 over earlier camera systems. CTIO now has an unsurpassed capability for high-resolution spectroscopy of faint objects.

National Radio Astronomy Observatory

NRAO is one of the world's major centers for radio astronomy. Operated by Associated Universities, Inc., NRAO has telescopes at three sites; its headquarters and one of its main data-processing centers are in Charlottesville, Virginia.

The two single-dish (91-meter and 43-meter) telescopes at Green Bank, West Virginia, are heavily booked by observers. Their interest is spurred by a new 5- to 25-gigahertz upconverter-maser receiver, especially effective for molecular studies, and the 300- to 1,000-megahertz, cryogenically cooled maser receiver designed for pulsar observation programs. Retrofitting of other receivers with cooled GaAsFET amplifers has begun, and marked improvements in stability have been shown over the older devices. Pressure has increased for use of the 43-meter telescope for very long baseline interferometry (VLBI) programs. Broadband Mark III recording systems with high information density are operational, and there has been increasing interaction with the European VLBI network.

At the new Very Large Array (VLA) near Socorro, New Mexico, the 27 antennas have now been used in all four antenna location configurations and the four standard frequencies have been used for continuum and polarization, limited spectral-line, and phased-array observations. An aggressive upgrading program is in process to improve the capacity of the VLA computer system now that the full complement of telescopes is in use.

Finally, the 11-meter, millimeter-wave telescope on Kitt Peak has an improved on-line computer system. The performance of two new receivers for the 1-millimeter wavelength atmospheric window is being evaluated, and engineering work is progressing on an improved and larger (12-meter) diameter surface for the antenna.

Sacramento Peak Observatory

SPO is one of the world's leading solar observatories. Located at an elevation of 2,760 meters in the Lincoln National Forest in New Mexico, SPO enjoys unusually good observing conditions, and is one of the best coronal observing sites in the continental United States, owing to extremely clear and unpolluted skies.

SPO has a number of unique solar research facilities and is a leader in applying advanced technology to solar observations. Its Vacuum Tower telescope produces very high resolution solar images, revealing the finest details in the solar atmosphere observable from the ground. An impressive array of auxiliary instruments permits extremely accurate measurements of velocity and magnetic fields in the sun's atmosphere. In the observatory's Big Dome, a new Low-Velocity Facility is being developed to measure large-scale flow patterns on the solar surface with unprecedented precision.

Both SPO staff and scientific visitors pursue an active and diverse program of observations and theoretical studies related to wave motions and oscillations in the solar atmosphere, limb-brightness variations, the physical structure of sunspots and magnetic fields in them, flare physics and buildup, development of active regions and mass ejection from those regions. SPO scientists have recently begun a new thrust in the area of solar/stellar astrophysics, using the sun as a basis for studying solar-type phenomena in a broad range of stars.

Magnetograms, velocity-field measurements, spectroheliograms, and spectra of active regions, flares, and the solar disk are all made routinely and provided to federal agencies and other interested observers. Scans of the coronal green line are used to prepare maps of coronal structure and to predict the appearance of coronal holes, which can influence geomagnetic activity.

Atmospheric Sciences

NSF supports fundamental research in the atmospheric sciences through seven grant programs and two facilities: the National Center for Atmospheric Research and the National Scientific Balloon Facility. The grant programs are as follows:

- *Aeronomy* focuses on understanding the nature of the atmosphere at altitudes where solar radiation and energy can alter the electronic bonds of constituent atoms, molecules, and ions.
- *Atmospheric chemistry* deals with the upper, middle, and lower atmosphere. Grants support basic research for laboratory, field, and modeling work on the natural cycles of nitrogen, sulfur, ozone, carbon, water vapor, and aerosols. Also studied are the effects of human activities on these cycles.
- *Climate dynamics* seeks a basis to predict climate variations and assess the way they affect human affairs. This means developing numerical models that can simulate future climate states.
- *Experimental meteorology* and *weather modification* stress experimental investigations of local and regional weather phenomena.
- *Global atmospheric research* is an international effort to learn about physical processes that affect the varying large-scale characteristics of the lower 30 kilometers of the atmosphere. The ultimate goal is better weather prediction.
- *Meteorology* supports research on the dynamics and physics of the lower atmosphere. It includes a large spectrum of activities ranging from studies of cloud microphysics and electrification through the basic dynamics of large-scale motions of the atmosphere.
- *Solar terrestrial* focuses on the release of energy by the sun, its propagation through the interplanetary medium, and its eventual impact on the atmosphere.

The National Center for Atmospheric Research

The National Center for Atmospheric Research (NCAR) and the National Scientific Balloon Facility (NSBF) are operated by the University Corporation for Atmospheric Research, a consortium of 46 U.S. and 2 Canadian universities under the principal sponsorship of NSF. NCAR is headquartered in Boulder, Colorado, and has a solar observing station at Mauna Loa, Hawaii. The balloon facility is in Palestine, Texas.

NCAR's mission is research to increase fundamental knowledge of the atmosphere. It also seeks to develop and provide major facilities and related services for the research community. Toward this end, the center starts, coordinates, and carries out research programs that require long-term cooperative efforts among scientists at NCAR and at universities, government laboratories, and other institutions.

Current major research efforts at NCAR are in atmospheric analysis and prediction, including climate studies and oceanography; atmospheric chemistry and aeronomy, including photochemistry and effects on the upper atmosphere; solar-terrestrial interactions; and convective storms, especially those leading to severe weather. NCAR also supports the atmospheric sciences community via state-of-the-art computing facilities, aircraft equipped for meteorological research, equipment to make sophisticated weather measurements in the field, and scientific ballooning for studies of the upper atmosphere and astronomy. The balloon facility supports about 75 balloon-borne experiments a year from its Palestine facility and from remote locations around the world.

NCAR also makes it possible for graduate and postdoctoral scientists to visit the center and participate in collaborative or individual research under its advanced study program. About 200 visitors spent a month or more in residence there during 1981.

A few of the many activities of the past year included improvement of a community climate model, a large-scale numerical model for use in climate studies; joint operation of the multiagency cooperative convective precipitation experiment in Montana during 1981; development of a computer model of the thermospheric layer of the atmosphere; successful long-duration flights of a new type of scientific balloon; and climate studies on the possible warming effects of carbon dioxide.

NCAR Community Climate Model

The National Center for Atmospheric Research has developed an initial version of a comprehensive numerical model designed to stimulate global and regional characteristics of the earth's climate. This community climate model (CCM) is intended for use by all members of the research community. It will be a useful tool to test the sensitivity of climate to changes such as an increase in atmospheric carbon dioxide. CCM has been designed to be computationally efficient and will focus on reproducing major features of atmospheric circulation and climate. Early tests show that the model simulates major atmospheric flow patterns fairly well, especially the energetics of atmospheric circulation.

The first version of this model has certain fixed features—for example, ocean surface temperatures, evaporation from land and ocean surfaces, cloud amount, and snow and ice cover. Given these nonchanging conditions, the model aims to measure how much of the variability in atmospheric circulation can be accounted for by major processes internal to the atmosphere itself. Early simulations show that modeled atmospheric variability with periods of 2 to 6 days matches the real atmosphere's variability almost exactly. For longer periods of 10 days to a month, the model simulates 80 to 90 percent of the real atmosphere's variability. A possible implication of these results is that only a small part of the changes of atmospheric motion at longer periods, and virtually none at shorter periods, is forced by changes in boundary conditions.

Physical processes included in the model are limited, but NCAR scientists and university researchers plan to update CCM by adding more realistic processes. Three major improvements are planned for the next version, probably in early 1982. These are the addition of an annual cycle of solar radiation, variable surface hydrology, and linkage of the atmospheric circulation to a simplified model of the oceans.

Planned investigations with the present and future CCM versions include the following:

- Quantitative comparisons between model simulations and observed climate statistics.
- Studies of the role the oceans play in the climate system.
- A look at the physical and dynamical processes important to regional climate change and at the effect of such processes as vegetative and snow-cover changes on the earth's surface.
- The interaction of atmospheric chemical and radiative processes with the global atmospheric circulation and climate.

Use of the CCM in these studies is expected to lead to more understanding of processes affecting the climate system, resulting eventually in better predictions of climate variability.

Cooperative Convective Precipitation Experiment

CCOPE is a major field experiment. Its aim: to gather data on the lifetime of convective clouds, from causal events in the planetary boundary layer with space to final precipitation and dissipation of the clouds. The surrounding atmospheric environment and initiating events must be understood to predict convective activity more accurately. Similarly, later developments within the clouds must be explained better before precipitation can be predicted or perhaps influenced.

In the past scientists have sought complete physical histories of convective storms,

Storms and their origins. Thunderstorms and rain showers are crucial to the summer water supply in most of the United States. Electrical charges in the atmosphere that can influence rainfall are a special focus of the cooperative convective precipitation experiment (CCOPE). It is managed jointly by the National Center for Atmospheric Research and the Department of Interior's Bureau of Reclamation.

including severe thunderstorms and hailstorms. The histories help show how these behemoths work—how the many processes interact to produce sometimes benign showers and sometimes damaging winds, hail, and torrential rain.

The field phase of CCOPE was done jointly by NCAR and the Department of Interior's Bureau of Reclamation. Other participants: the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the state of Montana, foreign research groups, and private organizations. NSF's experimental meteorology and weather modification program supported most of the 20 scientists from 13 universities who participated. CCOPE was conducted near Miles City, Montana, from 18 May to 7 August 1981. It succeeded in getting the most complete set of data yet collected on the life cycle of convective storms.

Participating in the field experiment were some 200 researchers and technicians from U.S. and foreign universities and government agencies. Also part of the project:

- A large array of equipment, including 13 research aircraft and 8 radars.
- A network of about 100 automated surface stations operated by the Bureau of Reclamation and NCAR.
- 5 rawinsonde stations provided by NASA and operated by Texas A&M University.
- Satellite data offered by Colorado State University through the Bureau of Reclamation.
- 8 time-lapse, cloud-photography sites operated by the Bureau of Reclamation and NCAR.
- Observation of ice-forming nuclei by NCAR.
- Electrical measurements by the University of Manchester (England), the University of Nevada, and the New Mexico Institute of Mining and Technology.
- Lightning measurements by the State University of New York at Albany and hail sampling by NCAR.
- Control-center facilities and logistics support provided by NCAR.

A sophisticated, computerized operations center handled radar and aircraft observations. This center tested an aircraft tracking system called MAPS (multiple aircraft positioning system), which provided continuously updated tracking by superimposing color-coded flight tracks on radar displays. More than 100 staff members from NCAR either were in residence at Miles City or visited the field site.

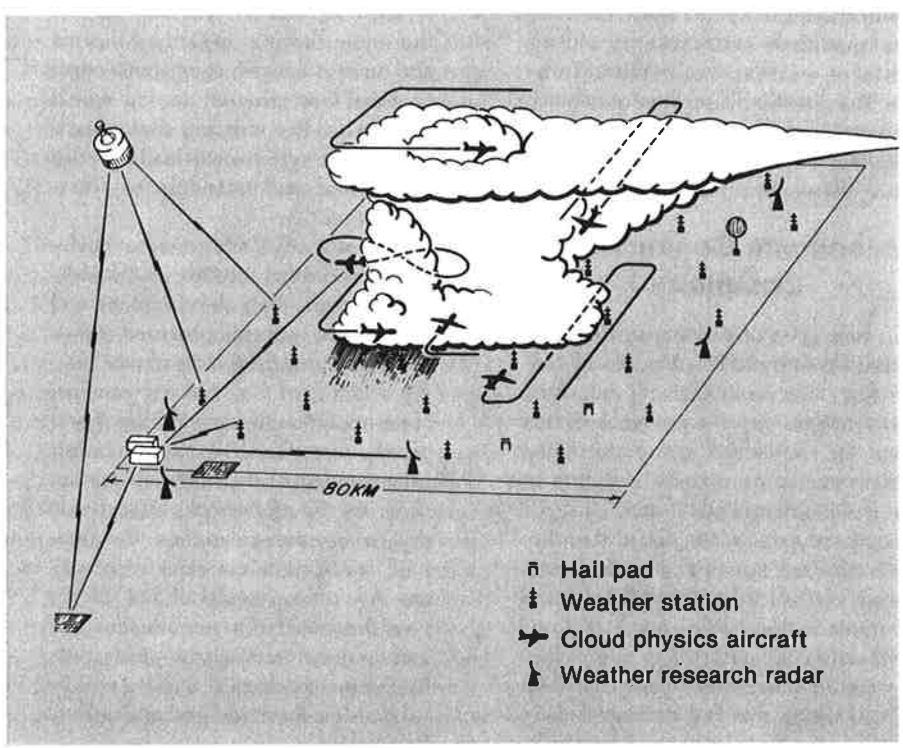
Some phenomena to be studied using the CCOPE data set include formation of ice particles and mixing of environmental air within clouds (entrainment); precipitation efficiency; evolution of atmospheric water vapor (hydrometeors) and storm-initiation processes; storm cell structure; and electricity in clouds and storms.

CCOPE investigators observed more "early storms" (clouds prior to the large cumulus stage) than ever before. These observations will help explain the formation of ice, hydrometeor growth, and entrainment processes. Several mature storms also were observed (the mature phase takes place as the storm, or convective complex, intensifies).

Other special CCOPE studies by university scientists included these:

- Field tests by Ohio State University scientists of a polarization radar technique that has the potential of making quantitative precipitation measurement and distinguishing solid from liquid phases.
- A field laboratory operated by Desert Research Institute scientists for routine monitoring of atmospheric aerosols, particularly cloud-condensation nuclei.
- Examination of the role of turbulence and the entrainment process on the distribution of cloud hydrometeor sizes and their evolution, by scientists from the Universities of Manchester (U.K.) and Washington.
- Airborne measurements of the distribution and flux of ozone in the convective boundary layer and in the vicinity of convective storms, by Colorado State University scientists.
- Measurements of the dissipation and propagation of kinetic energy generated in early cumulus convection, by a University of Wisconsin scientist.

The data from CCOPE should provide a much-needed description of convective



The scope of CCOPE. This schematic of the CCOPE field experiment shows the approximate locations of radar installations and weather stations and the flight patterns of some of the participating aircraft.

CCOPE Aircraft

Agency	Aircraft	Function
1. Canada NAE	Twin Otter	Cloud physics (−5°C level)
2. DOI/Bu Rec	King Air (U. of Wyoming)	Cloud physics
3. NSF/NCAR	Cessna 182 (leased)	Tow plane for sailplane
4. NSF/NCAR	Queen Airs (2)	Air motion and turbulence measurements
5. DOI/Bu Rec	Cessna Citation II (U. of N. Dakota)	Quantitative cloud photography
6. NSF/NCAR	Sabreliner	High-altitude cloud reconnaissance
7. NSF	T-28 (S. Dakota School of Mines)	Mature storm penetration (−10°C level)
8. NSF/NOAA	Schweizer 2-32 sailplane	Cloud physics
9. DOI/Bu Rec	Queen Air (U. of Wyoming)	Cloud physics
10. NASA	WB-57F	Cloud and surface radiative measurements
11. NASA	Convair 990	Remote air sensing
12. NSF/NCAR	Cessna 180 (leased)	Chaff dispensing
13. NSF	Aerocommander (U. of Nevada)	Cloud physics (−15°C level)

Legend

CCOPE: Cooperative convective precipitation experiment
NAE: National Aeronautics Establishment
DOI/Bu Rec: Department of Interior/Bureau of Reclamation
NSF: National Science Foundation
NCAR: National Center for Atmospheric Research
NOAA: National Oceanic and Atmospheric Administration
NASA: National Aeronautics and Space Administration

clouds as integrated systems. CCOPE results will also mean a better understanding of what modulates storm severity and the potential of weather-modification techniques. Results should improve our ability to predict thunderstorms and other severe weather—high winds, damaging hailstorms, and tornadoes—over the U.S. high plains.

Mesoscale Convective Complex

This new class of weather systems has been discovered by Robert Maddox of Colorado State University. Using enhanced infrared images from a geosynchronous satellite, he found that many individual thunderstorms, previously thought to occur independently, were part of large organized circulations. Organized thunderstorm complexes, lasting 12 or more hours, were seen to affect areas of the United States comparable in size to the states of Iowa and Missouri combined. Many of the complexes resulted from interactions between groups of storms that first developed along the eastern slopes of the Rocky Mountains, while others formed over the plains.

Locally, mesoscale convective complexes, or MCCs, often produce a variety of severe weather phenomena such as tornadoes, hail, intense electrical storms, and flash floods. But these long-lasting, organized storms also may serve as a highly significant source of beneficial precipitation in the wheat and corn belts. Recognizing these large-scale convective systems will lead to better forecasting and understanding of atmospheric motion.

Theoretically, MCCs can be resolved by operational numerical forecast models now in use; however, their development and evolution are not explicitly predicted. When MCCs develop, underestimates of precipitation by a factor of five are not unusual from operational numerical models. Forecasters who recognize MCCs can monitor their development and give better weather forecasts. As the physics of convectively driven complexes is understood, the capability of modeling them effectively will emerge. A working model of MCCs has been synthesized from satellite imagery and conventional surface and radar data. Continued meteorological studies will be used to evaluate the model and understand its physics.

Mesoscale convective complexes find their origin typically in regions where conditions favorable to convection occur and where local topography or heat sources give rise to thunderstorms. This initial thunderstorm development is fostered by low-level convergence of warm moist air that then rises. The transition to a large, highly organized system usually occurs in the early evening.

As MCCs develop, they draw air toward their centers, enhancing upward motion and convection. Upper-level outflow produces cloud shields some 100 times the size expected from a single thunderstorm. Once developed, an MCC begins to move, interacting with and modifying its surrounding atmospheric environment in ways that may affect the evolution of meteorological features over much of the United States.

Most systems grow to their maximum size after midnight and persist into the morning. An MCC dissipates when new convective elements stop developing because their fuel supply—the low-level moisture convergence—is completely used or cut off. Although the demise of the intense, highly organized convective system is relatively abrupt, residual cloudiness and light shower activity may persist for hours and affect large regions of the eastern United States.

Understanding the life cycles, meteorological characteristics, and environmental interactions of MCCs will help elucidate many aspects of convective weather phenomena. Prospects for expanding our knowledge of the MCCs are good, since time and space scales of these systems and their frequent occurrence over the central United States make them amenable to detailed observation and investigation.

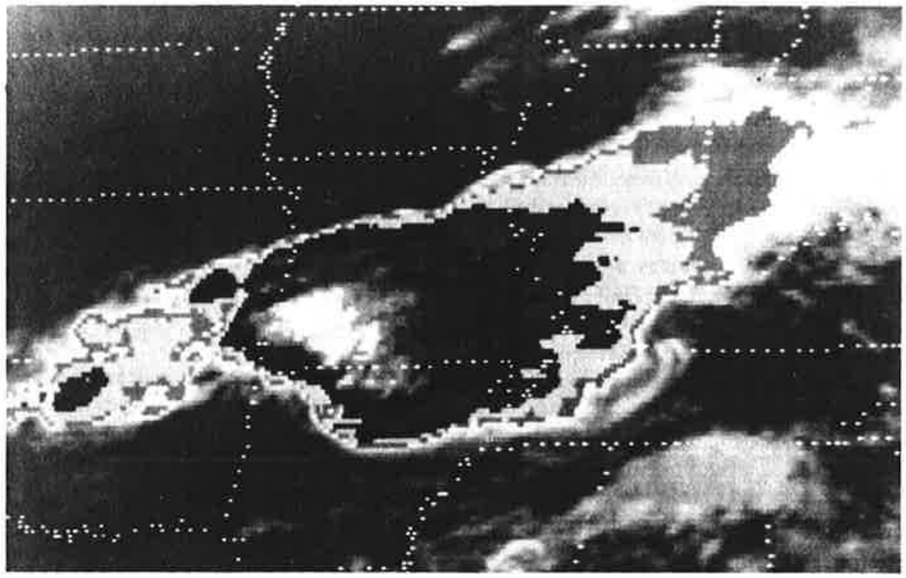
Paleo-Climate/Solar Distance

As a result of studying the ancient shorelines of lakes in northern Africa and northwest India, paleoclimatologists have concluded that the climate of these semiarid areas was significantly wetter some 8,000 to 10,000 years ago than it is today. John E. Kutzbach of the University of Wisconsin's Center for Climatic Research has identified the likely cause of this wetter period.

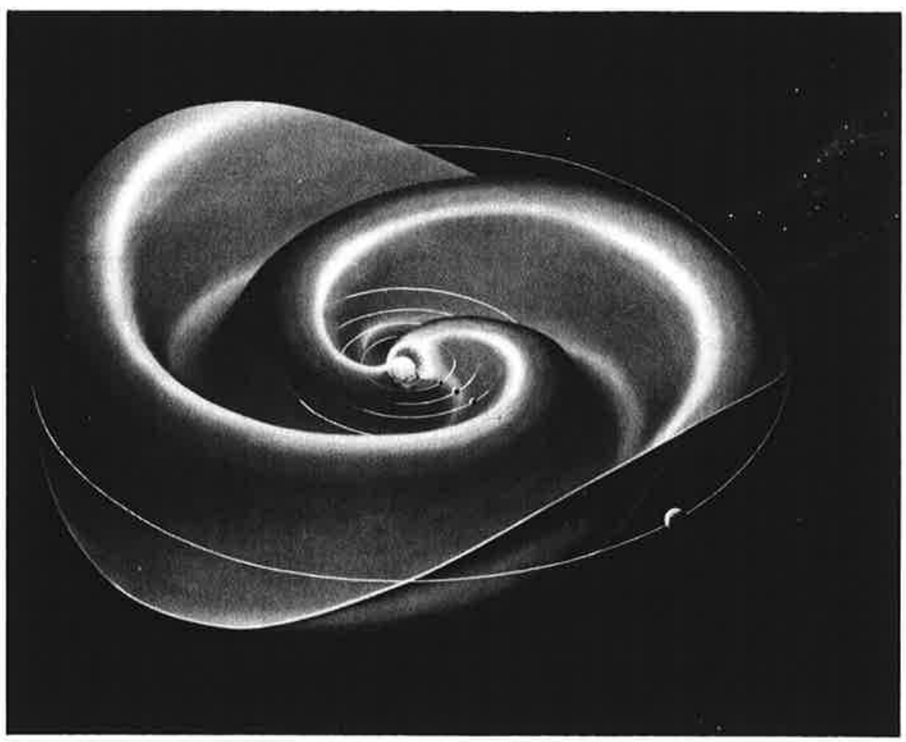
Kutzbach notes that the Serbian scientist Milutin Milankovitch showed that the intensity of solar radiation reaching any point on the earth's surface varies over periods of thousands of years because of changes in the earth's orbit about the sun. Currently, the earth is slightly closer to the sun in January than in July, but 9,000 years ago the earth was closer to the sun in the Northern Hemisphere summer and farther away in the winter. As a result, the summertime heating and wintertime cooling of the large continents in the Northern Hemisphere were slightly more pronounced 9,000 years ago than today.

Using a numerical model of the global climate system, Kutzbach has shown that, when the seasonal incidence of solar radiation is changed to that of 9,000 years ago, the model indeed predicts greater seasonal temperature contrasts over Northern Hemisphere continents. Furthermore, the model indicates that these increased temperature contrasts lead to enhanced monsoonal circulations in certain areas, such as Northern Africa and India. It is well known that the monsoon circulation in these regions causes most of the total annual precipitation. It is not surprising, therefore, that the model shows significantly greater rainfall in those areas 9,000 years ago, compared with the present.

Increases indicated by model results agree closely with those deduced from higher lake levels 9,000 years ago. Consequently, our understanding of at least one process that affects climate over longer periods of time has been improved by this study.



New weather systems. This mesoscale convective complex (MCC) is a new class of weather system, discovered by a University of Colorado scientist. The outline of an extensive cloud shield associated with an MCC is visible in this enhanced infrared image obtained by satellite on July 15, 1978, at 11 p.m. CST. The cloud shield stretches from Kansas and Nebraska on the west to Indiana and Ohio on the east. The white areas outlining and within the MCC cloud shield show temperatures below minus 60 degrees centigrade. Damaging winds, hail, heavy rain, and associated flash floods were reported as this MCC developed and evolved. Scientists believe that recognizing these large-scale systems will lead to better weather forecasts.



Solar skirt. A magnetically neutral sheet, depicted here as a warped heliosphere, separates the solar magnetic field that is directed away from the sun (above the sheet) from the region below, where the field is directed toward the sun. This solar phenomenon affects the orbiting planets—contributing, for example, to geomagnetic storms. Scientists hope that future work in establishing solar-terrestrial connections like this one will help us predict atmospheric phenomena better, anticipate magnetic effects on power transmission lines, and ensure the safety of astronauts.

Solar-Terrestrial Connections

The sun provides the energy that drives the solar system. Most of that energy is transmitted with a steady flux of light that, in the case of the earth, maintains a hospitable atmosphere for human existence. Nevertheless, a small but significant fraction of the sun's output is in the form of x-rays, radio waves, energetic particles, and magnetic fields. These various energy forms are highly variable, due to variations in solar activity such as sunspots and solar flares. This activity experiences an 11-year cycle, the peak of which was last seen in 1980-81.

The sequence of events relaying these energy forms to earth depends on the solar wind, a supersonic stream of hot gas with temperatures as high as a million degrees. The solar wind affects and surrounds the magnetic field of the earth, creating the so-called magnetosphere. While separate parts of this solar-terrestrial connection have been studied and partially understood for some time, it is only in the past year that the first steps have been taken to model the complete process.

Using a numerical model at the University of Alaska, Syun-Ichi Akasofu has reproduced some of the features of the magnetic disturbances propagating to earth. These disturbances are superimposed on the steady solar magnetic field that reaches into interstellar space. The magnetic field determines what effect solar flares have on the earth's upper atmosphere. By knowing the magnitude of a flare, its location on the sun, and the position of the earth in space, Akasofu can infer the three-dimensional structure of the solar wind and its distortion of the solar neutral sheet as it propagates outward from the sun.

Scientifically, this work helps researchers overcome the mathematical and computational difficulties that have prevented a fully three-dimensional treatment of the solar wind. Second, it allows them to calculate the energy input into the magnetosphere in order to predict whether or not a geomagnetic storm will occur, with its resulting disturbances of the polar upper atmosphere—for example, aurorae and radio transmission interference. Finally, scientists hope that modeling the whole solar-terrestrial connection will lead to a predictive capability similar to weather forecasts and one that will have a positive impact on communications, power-line breakdown, astronaut safety, and resource exploration in polar regions.

Earth Sciences

In September 1980 the International Council of Scientific Unions (ICSU) proposed an interdisciplinary research program to study the dynamics and evolution of the lithosphere—the outer 100 kilometers of the solid earth, including its crust and a portion of the upper mantle. One goal of the program is to strengthen the interaction between basic research in this area and its application. The program recognizes that geology, geophysics, geochemistry, and geodesy contribute greatly to mineral and energy resource exploration and development, to the mitigation of natural hazards, and to environmental maintenance.

The plate tectonics revolution has given us the beginnings of a consistent, comprehensive perception of how the earth works. The earth is a dynamic body with material in the mantle moving slowly by convection. That convection is expressed at the surface by movements of crustal plates at rates of a few centimeters per year, or tens of kilometers over a million years. New ocean crust is created where hot buoyant material from the mantle rises to the surface, spreads laterally, and cools to produce the rigid crustal plates. Older ocean floor is destroyed where the edges of some plates move under others and sink into the mantle.

This theory of plate tectonics was derived largely by study of the ocean basins, which record the dynamic history of the earth for only about the last 200 million years. The time has now come to reinterpret the structure and evolution of the more complicated and older continental crust in terms of the plate tectonics theory. This is a major focus of the ICSU lithosphere program and of the U.S. Geodynamics Committee as well.

The plate tectonics theory has changed the way this kind of research is done. A multidisciplinary approach—in which geologists, geophysicists, and geochemists make a concerted effort—is becoming more common, and science is benefiting.

The renewed interest in the continental crust will lead to research on mineral and fossil fuel resources, waste disposal, and the prediction of earthquakes and volcanic eruptions. It will also help answer some fundamental scientific questions about the earth, including these:

- What is the heat engine causing mantle convection and plate tectonics?
- Why does the earth's magnetic field reverse itself periodically?
- What causes intraplate earthquakes like the Charleston, South Carolina, earthquake of the last century?
- What occurred during the first half-billion years of earth evolution?
- What caused pulses in the rate of biological evolution?
- What caused the extinction of the dinosaurs and other life forms—was it the impact of an asteroidlike body, as has been suggested?

The answers to these questions are of fundamental scientific importance. They require more and more complex instrumentation—it is not unusual for a department of geological sciences at a university to own equipment worth several million dollars. The field is growing faster than ever before, stimulated by exciting science and societal needs, so that research of increasingly higher standards is being supported every year.

Coral Banding and Plate Tectonics

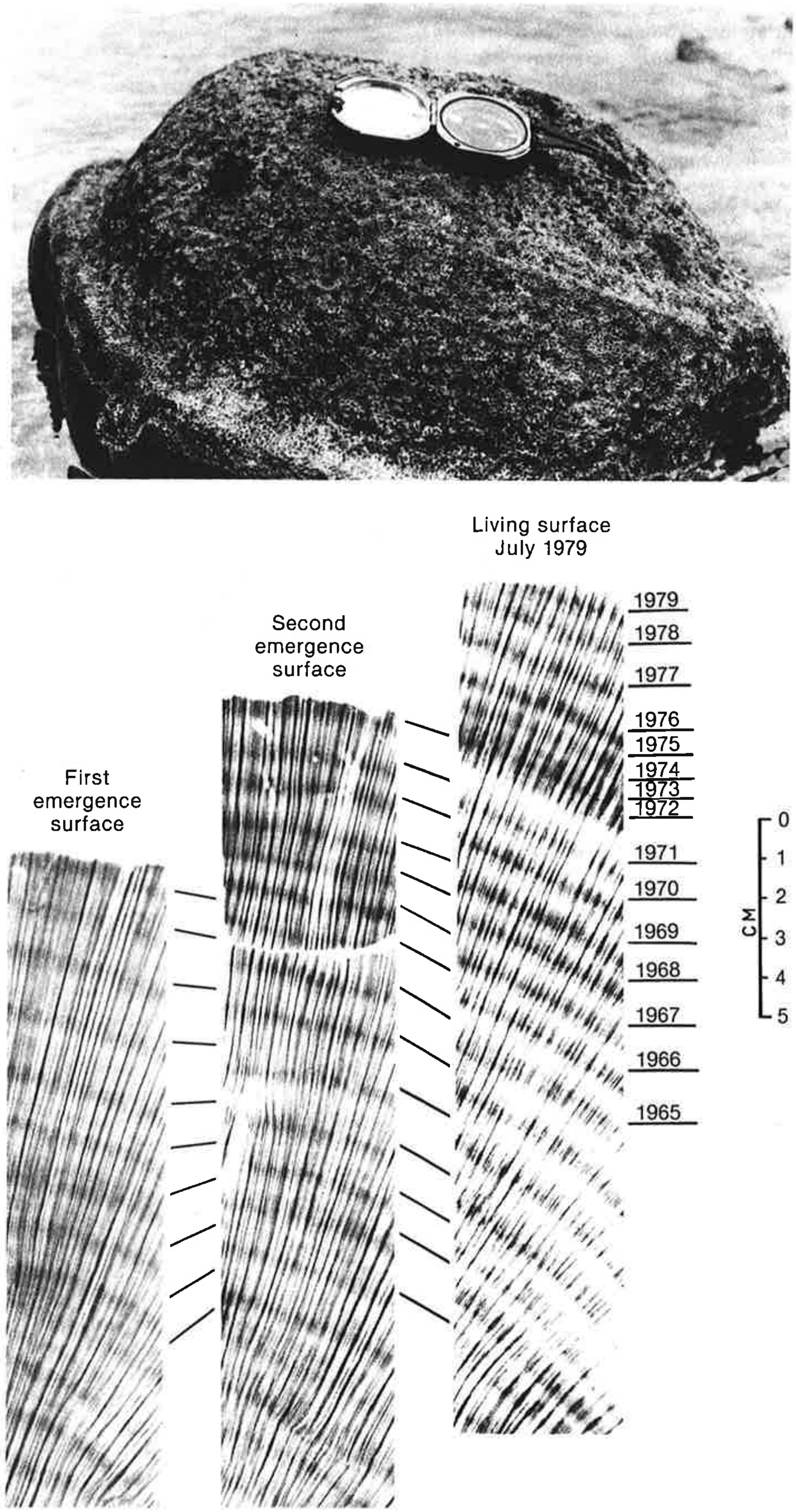
Major and minor changes in climate and other features of the environment are recorded by the periodic addition of growth bands in tissues of a wide variety of organisms, including trees, mollusks, and corals. These cyclic growth bands give evidence of such things as temperature fluctuations during ice and changes in the rate of rotation of the earth during past geological times. A recent application is the use of annual layering in some species of modern corals to throw light on certain plate tectonic processes. Among these are the frequency and rates of vertical movement associated with subduction zones at converging plate margins.

Past movements of land areas with respect to sea level are reflected by marine terraces along many shorelines of the world. These raised beaches may be caused by actual tectonic motions, by fluctuations in sea level resulting from waxing and waning of continental ice sheets, or by warping of the geoidal surface.

Raised coral terraces on islands in Vanuatu (formerly the New Hebrides) in the southwest Pacific record recent tectonic uplift in that island arc, related to subduction of the Indian-Australian plate beneath the Pacific plate. Amounts of uplift of the thin western edge of the Pacific plate during the past few decades are determined by measuring the differences in elevation between coral heads that were killed by emergence and the highest related forms still living in the intertidal zone.

The number of annual growth bands added to the still-living zones since partial emergence of some individual coral heads reveals the years in which recent uplifts occurred. Episodes of uplift shown by the corals have been correlated in a number of instances with seismic records and historical accounts of specific earthquakes. This provides precise methods of measuring the frequencies and amounts of uplift associated with seismic activity in the subduction zone for which other records are not available.

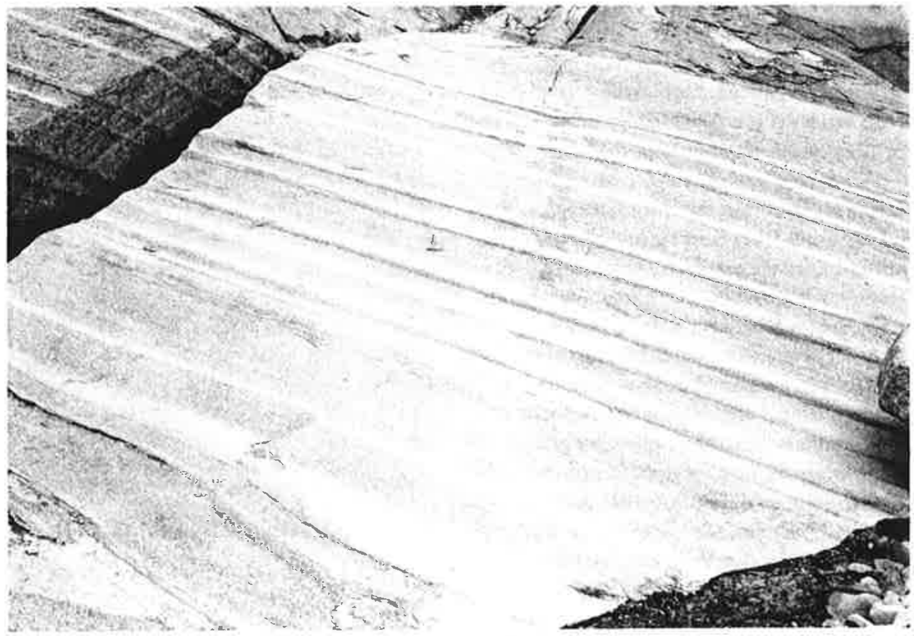
Although the growth bands are not as clearly defined as those used in tree-ring dating techniques, progress has been made in cross-dating among separate coral heads. The longevity of such heads is in the range of 100 or more years, so the possibility of



Growth bands. The surfaces—both living and dead—of this coral head reveal cyclic growth bands that give a history of sea-level changes in the Vanuatu (New Hebrides) region of the southwest Pacific. These changes are associated with seismic and tectonic activity there. The dome at the top of the photograph, a dead surface, is thought to be tied to a 1965 earthquake; the ledge on the left front, also dead, may have emerged during a similar event six years later. Coral polyps are still living around the base. At the bottom are x-radiographs of cores taken from the various surfaces. The curving layers can be matched in a way similar to that used in tree-ring chronologies. Here the bands of lesser density reflect optimal growth conditions that occur during the winter in this area.

extending the dating of seismic-related uplifts beyond a few decades is promising.

The Vanuatu arc has been the site of extensive cooperative studies on seismology, tectonics, and sea-level changes by scientists from New Caledonia, Cornell University, and the University of Texas. Estimates on amounts of Quaternary uplifts and sea-level fluctuations have been based on radioactive dating of the older terraces and use of precise leveling and tiltmeter measurements. The highest surfaces on the main islands are believed to relate to a climatically controlled high sea level of 125,000 years ago. Lower terraces may be the result of both tectonics and sea-level changes. Detailed studies of the elevations and degrees of tilting of the surfaces are aimed at distinguishing between events related to climatic changes and those caused by interactions between the colliding plates.



Layered igneous intrusions. These large, crystallized magma bodies often show complex banding patterns that cannot be explained by classical mechanisms. Earth scientists are investigating them not only for their intrinsic geological interest but also because they are major deposits for such materials as chromium, nickel, and the platinum-group elements.

Geochemical Dynamics

Recent experimental and theoretical studies of coupled heat- and mass-transport phenomena in cooling, crystallizing magma bodies are providing new insights into and understanding of the formation and evolution of igneous rocks.

Traditionally, partial melting and fractional crystallization have been invoked to explain the differences in chemical compositions in genetically related igneous rock suites. Over the past 50 years, a major thrust of geochemical research has been to determine crystal-melt equilibrium relations. This includes both phase equilibria and trace-element distributions, under conditions of temperature, pressure, and composition typical of igneous environments. Such equilibrium relations can satisfactorily explain the compositional variations in many igneous rock suites. However, there are obvious and important occurrences that remain enigmatic.

Among these phenomena are layered igneous intrusions or large magma bodies that crystallize in place. They often show complex patterns of compositional banding that cannot be explained by simple fractional crystallization with gravitational settling. These phenomena are now being addressed by nonequilibrium models incorporating kinetics of heat and mass transfer and flow properties of magmas accompanied by chemical differentiation.

In silicate melts—common magmas—heat diffuses much faster than individual atoms. So it is possible that crystallization at the walls of a magma chamber may create a buoyant boundary layer of low-density, highly differentiated liquid that streams upwards to accumulate as a gravity-stabilized zone at the top of the chamber, while the remainder of the magma convects normally below. This mechanism is capable of producing relatively large volumes of highly differentiated liquid with only a small degree of crystallization. Eruption of such a system would begin with an explosion of the volatile, silicon-rich, and differentiated magma, followed by more mafic lavas (those rich in magnesium and iron). Feeder vents tapping different levels of the chamber could result in both types of lava erupting simultaneously from different vents.

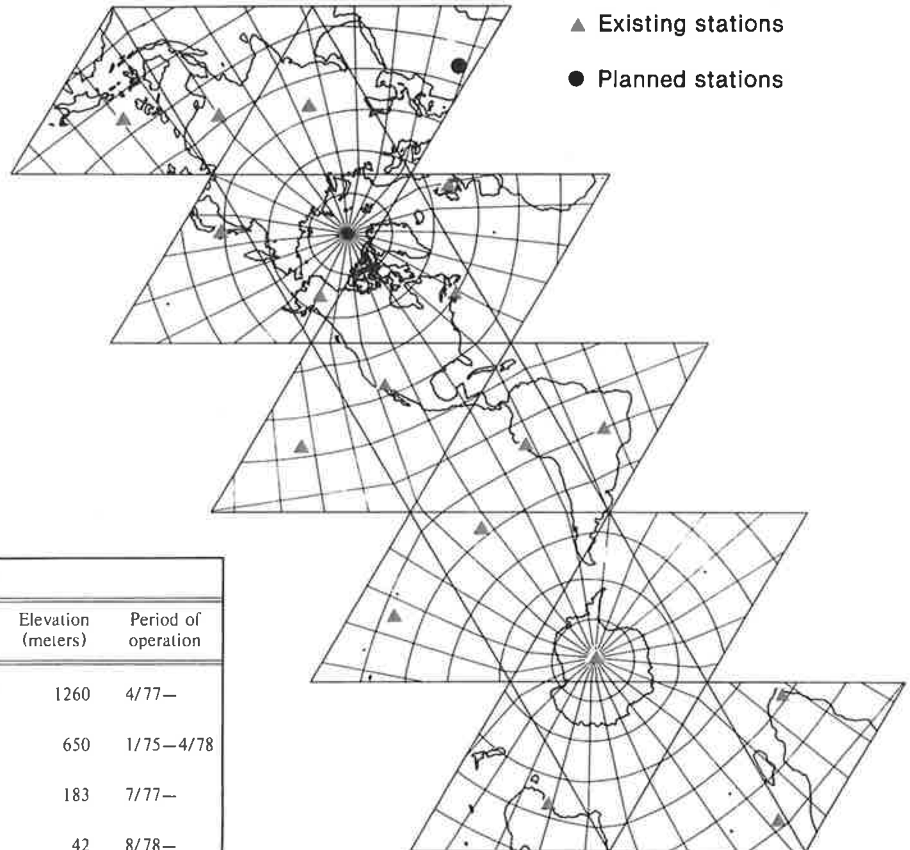
These large differences in the rates of diffusion of species (including thermal vs. chemical) can also result in what is called double-diffusive convection, giving rise to composition/density stratified magmas. *In-situ* crystallization of such a stratified body could explain many aspects of layered igneous intrusions. In addition to their intrinsic geological interest, layered igneous complexes may constitute major ore deposits for strategic materials such as chromium, nickel, and the platinum-group elements.

Project IDA

Project IDA (International Deployment of Accelerometers) is an NSF-supported global seismic network specifically designed to record the earth's normal mode vibrations. These are vibrations of the entire earth set into motion by large earthquakes, like the ringing of a bell when struck. Studies of this phenomenon yield information about the internal structure of the earth as well as the earthquake mechanism itself. Observationally what is required is a global network of instruments that respond to these very long period (several minutes to an hour) oscillations.

The idea for such a network evolved from two important developments of the late 1960s. First, progress in the theory of normal modes and its application to available observations made it clear that such studies could provide considerable new knowledge, both on earth structure and earthquake mechanisms. Second, the development of feedback accelerometers of exceptionally low noise provided a means to obtain this very long period data from relatively frequent earthquakes.

The plan involved converting existing underwater gravimeters to very long period seismic sensors and placing some 20 of



Project IDA Stations

Location	Code	Latitude	Longitude	Elevation (meters)	Period of operation
Brasília, Brasil	BDF	15°39′50″ S	47°54′12″ W	1260	4/77–
Canberra, Australia	CAN	35°19′15″ S	148°59′55″ E	650	1/75–4/78
College, Alaska, USA	CMO	64°51′36″ N	147°50′06″ W	183	7/77–
Easter Island, Chile	EIC	29°09′29″ S	109°26′04″ W	42	8/78–
Erimo, Japan	ERM	42°00′54″ N	143°09′26″ E	40	8/80–
Eskdalemuir, Scotland, UK	ESK	55°19′00″ N	3°12′18″ W	242	9/78–
Garm, USSR	GAR	39°00′00″ N	70°19′00″ E	1300	9/76–
Guam, Mariana Is.	GUA*	13°32′18″ N	144°54′42″ E	230	7/79–
Halifax, N. S., Canada	HAL	44°38′16″ N	63°35′30″ W	38	4/76–
Kipapa, Hawaii, USA	KIP	21°25′24″ N	158°00′54″ W	70	9/77–
Kunming, PRC	KMY	25°08′54″ N	102°44′49″ E	1952	10/80–
Naña Peru	NNA	11°59′15″ S	76°50′32″ W	575	6/75–
Piñon Flat, Calif., USA	PFO	33°36′33″ N	116°27′19″ W	1280	2/76–
Rarotonga, Cook Islands	RAR	21°12′45″ S	159°46′24″ W	28	10/76–
Mahé, Seychelles	SEY†	4°36′54″ S	55°29′27″ E	270	1/80–
South Pole, Antarctica	SPA‡	90°00′00″ S		2927	1/79–
Sutherland, RSA	SUR	32°22′47″ S	20°48′04″ E	1770	12/75–
Adelaide, Australia	TWO	35°01′57″ S	138°34′41″ E	165	4/78–

*From 7/79 through 10/79 this station was located at 13°35′18″ N, 144°51′42″ E.

†From 1/80 through 10/80 this station was located at 4°40′ S, 55°29′ E.

‡Instrument installed and operated by UCLA; the date given here is the time at which an IDA filter and recorder were added.

IDA stations. Project IDA (international deployment of accelerometers) is a global seismic network to record the earth's normal vibration modes—those set off by large earthquakes. Seventeen stations were operating in 1981, as listed here and shown on the map. Normal mode studies give information about the internal structure of the earth as well as earthquakes. In addition, IDA data have helped scientists better understand tides, seismic ocean waves (tsunami), and the lithosphere.

these systems in a worldwide network. The number of stations planned was determined by the typical wavelengths of seismic waves at normal mode frequencies, by the number of instruments available at a reasonable cost, and by the desire to keep routine maintenance and data processing from becoming a major undertaking.

With partial support from NSF, the first station was installed in late 1974 in Canberra, Australia. The most recent installations, all during the past year, are at these sites:

- Kunming, the capital of Yunnan Province, People's Republic of China (part of the official NSF/State Department/ U.S. Geological Survey Seismological Bureau).
- Mahe, Seychelle Islands.
- Erimo, on the island of Hokkaido, Japan (replacing the station at Yuzhno-Sakhalinsk, USSR).

This brings the network to 17 stations currently operational, including the UCLA station at the South Pole that provides Project IDA with data. Two or three more stations are planned. These will most likely be in Alert, NWT, Canada, to provide needed high-latitude coverage; Tamanrasset, Algeria; and a second station in China.

Although the study of the earth's normal modes was the primary motivation for this project, data from the IDA network have contributed to recent advances in several areas. These include regional loading effects on the bodily tides of the earth, very low frequency oscillations of the earth's core, the search for "silent" earthquakes, regional studies of heterogeneity and anisotropy in the lithosphere, and tsunami warnings from earthquake source mechanisms.

Ocean Sciences

The ocean sciences apply the principles and techniques of biology, chemistry, geology and geophysics, mathematics, and physics to further our understanding of the ocean, marine life, and the sea floor. During 1981 there were changes in the legal status of the ocean and in our understanding of major ocean and sea-floor processes. These have increased both opportunities and demands for ocean sciences. Various international and national arrangements are transforming about a third of the ocean from a resource now freely accessible to all to a resource under the strict control of coastal states. For ocean scientists this limits their unrestricted access to scientifically important coastal areas and will impede scientific progress there.

Despite this limitation, oceanography is entering an exciting and challenging era. Much of the preliminary exploration of ocean basins has been completed. The International Decade of Ocean Exploration (IDOE), from 1970 through 1980, made major contributions to our knowledge of the oceans and also changed the way the ocean is studied. The IDOE encouraged new forms of interdisciplinary and international projects to look at ocean processes. Scientists are now better able to study global ocean activity on appropriate scales with new techniques and instruments, such as satellites, remote-sensing instrumented buoys, and powerful computers.

Despite these advances, our understanding of ocean processes is still fragmentary. Oceanographers have not had the new techniques and instruments long enough to observe ocean basins and processes on appropriate space and time scales.

Most ocean processes are highly variable, and studying them demands several new approaches and tools. One of these, the hydraulic piston corer, brings up undisturbed samples of soft sediments from the deep sea. These samples are used in studies of long-term variations in ocean conditions, such as those that controlled climate in the past. And for the first time, instruments are providing short time-scale, *in-situ* measurements of highly variable features such as near-bottom currents. The high precision achieved through these new instruments is posing new questions, such as the relative importance of previously overlooked microorganisms in open-ocean food chains.

These tools and techniques have accelerated the discovery of ocean processes in the past five years. Some of the most striking discoveries were deep-sea hydrothermal vents and their unusual communities of marine organisms. Recent investigations have shown that chemical reactions between seawater and hot, newly formed oceanic crust control the chemical composition of seawater and form strategic metal deposits on the sea floor. It has also been postulated that unique biological communities of organisms based on a hydrogen sulfide food chain and found near the active hydrothermal vents may have been precursors to life on earth.

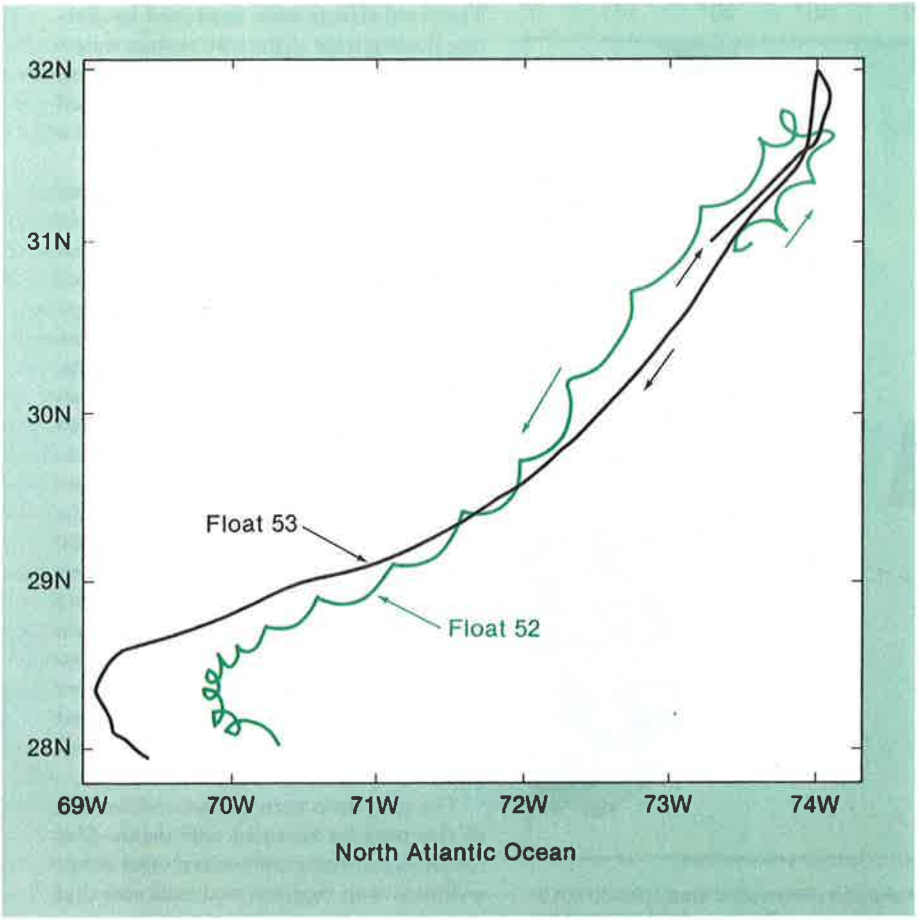
There are also recent major advances in open-ocean dynamics. Among these are the discovery of huge, swirling water masses or eddies, tens to hundreds of kilometers in diameter, in the ocean interiors. These features are more energetic, widespread, and persistent than previously thought. Now new questions are raised about ocean circulation and the distribution of heat and energy that ultimately affects continental weather and climate. For example, what is the energy source of these eddies? How and on what time scale is energy transferred into and out of the eddies? And what is their role in the net poleward transport of heat by the oceans?

NSF supports about half of all academic ocean science research in the United States and about two-thirds of all basic ocean research. Other sources of support are the Office of Naval Research, the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy, the Bureau of Land Management, and the U.S. Geological Survey.

Small Eddies in the North Atlantic

In May and June of 1978, as part of a joint American and Soviet study of ocean eddies, American scientists carried out a program of intensive measurements in the western North Atlantic. Results from this program have recently been analyzed. The field program was designed to measure accurately the motions and pressures in order to determine local force balances associated with eddies. Techniques used included sound-fixing and ranging (SOFAR) floats, current meters, and shipboard determinations of water properties.

SOFAR floats are neutrally buoyant and can be positioned at predetermined depths. As they move with the water, they emit acoustic pulses at regular intervals so that their positions can be tracked. Two floats, part of a larger cluster, were launched near



A pair of SOFAR tracks. Sound-fixing and ranging floats are important new tools to study motion and pressure in the sea. As they move with the water, the floats emit regular signals so their position can be tracked. Here two neighboring floats are shown in the North Atlantic. One (52) is trapped in a small eddy discovered during the POLYMODE experiment, an effort to measure local current movements and changes. Dots along the tracks mark float positions on subsequent days.

each other at a depth of 700 meters. Their tracks showed markedly different behaviors. One had a smooth trajectory, characteristic of the behavior of the larger cluster, while the other had a cycloidal track. This difference in behavior is striking and illustrates a major finding of the experiment: the discovery of small eddies.

These small-scale, pancake-shaped features were discovered in the upper or mid-thermocline and in the deep water well below the ocean surface. They have radii on the order of several tens of kilometers and a limited vertical extent—from a few hundred to more than a thousand meters. These small eddies have a whirling motion that holds the seawater within them, together with its heat, salt, and other dissolved properties, as the eddies travel through the ocean. Their most remarkable aspect is their apparently long lifetime, indicated by the distinctly anomalous properties of the water in them as compared to that of the surrounding sea. Simple calculations suggest that the eddies must have traveled and maintained themselves over thousands of kilometers and periods of one to several years.

The first of these small, mesoscale features was in fact observed before these experiments by floats and hydrographic measurements in a location near the Bahamas. The lens was nicknamed "Meddy" because it contains water that was of Mediterranean Sea origin—over 4,000 kilometers away. This is inferred by comparing the water properties within Meddy to those at other locations in the North Atlantic. Since water properties change slowly in the ocean interior as a water parcel moves along, they can be used to identify source regions; each of those regions contributes unique properties due to local, boundary-mixing processes. The temperature and salinity properties for 20 stations nearby but external to Meddy are significantly different from Meddy's; it resembles Mediterranean water found across the ocean basin. No other source region in the North Atlantic has the required water properties.

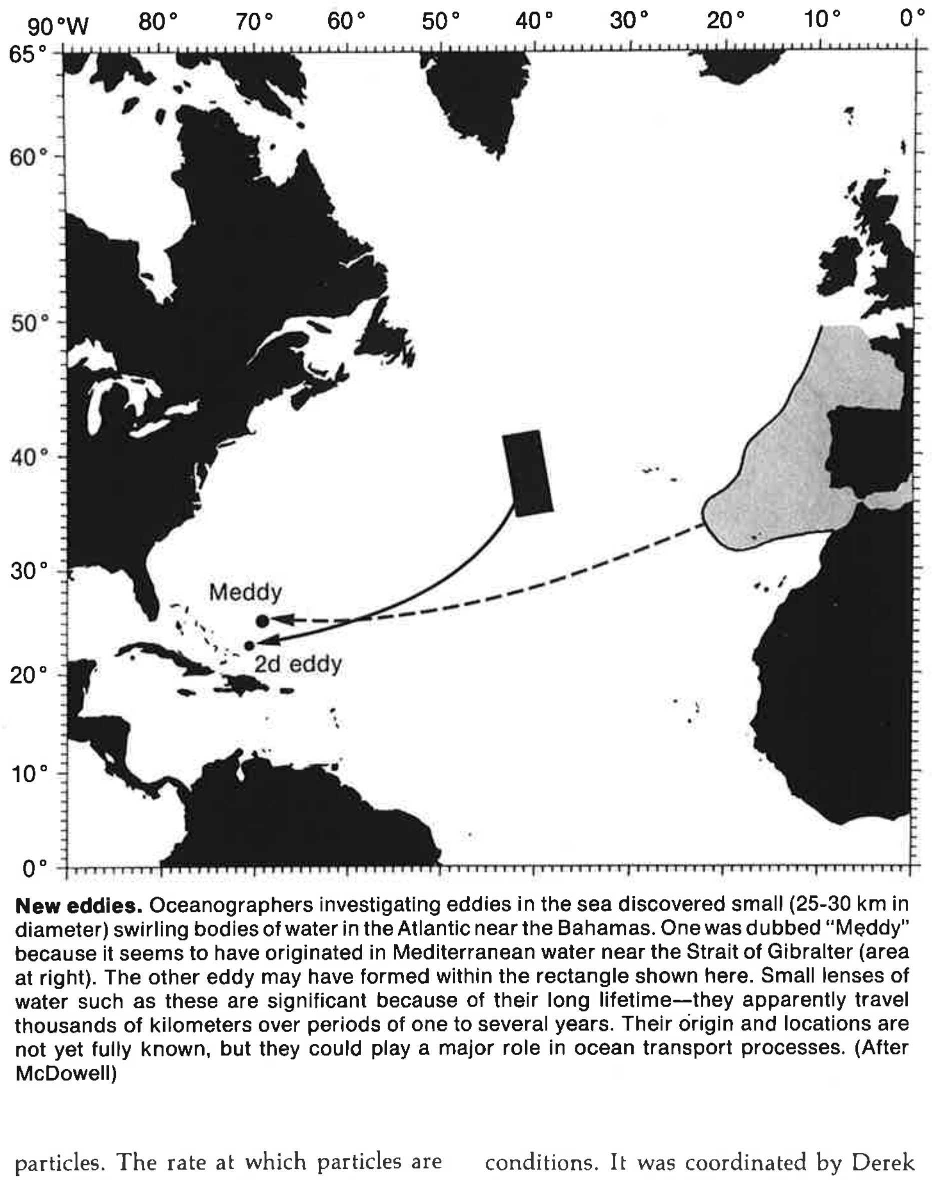
It is not yet known how frequently or where small eddies occur. On the basis of those identified in the past few years, their distribution in space and time is irregular. Although source regions can be inferred from the water properties, the generation process is still a matter of speculation. A possible mechanism is instability in currents as they interact with topographic features, resulting in the spinoff of small eddies.

Another unknown is the role these eddies play in the general circulation and transport of properties within the ocean. Since their properties differ significantly from those of the surrounding waters, the features could play a major role in transport and stirring within the ocean. But these questions are yet to be answered.

Vertical Flux of Particulate Matter in the Oceans

Understanding the flux of particles throughout the ocean is fundamental to many basic and applied marine chemical research programs. Particles, along with substances incorporated in them, are transported by gravitational settling that becomes a significant process for distributing mass. In contrast to the slow vertical movement of chemically dissolved material, it is now known that there are particles formed in or deposited on the ocean surface that drop through 5,000 to 6,000 meters of water in only a few days to a few months.

The distribution of particles in the ocean is highly skewed toward the very small sizes (only a few microns), which settle quite slowly. A typical particle of 1 to 2 microns might take 10 years or more to move through the water column. Large particles of greater then 50 microns are exceedingly rare. However, because they settle so rapidly, they contribute most of the vertical flux of materials to the deep ocean. These particles contain surface-produced organic matter, carbon fixed by photosynthesis, and reactive heavy metals and other chemicals that are readily absorbed by ocean



New eddies. Oceanographers investigating eddies in the sea discovered small (25-30 km in diameter) swirling bodies of water in the Atlantic near the Bahamas. One was dubbed "Meddy" because it seems to have originated in Mediterranean water near the Strait of Gibralter (area at right). The other eddy may have formed within the rectangle shown here. Small lenses of water such as these are significant because of their long lifetime—they apparently travel thousands of kilometers over periods of one to several years. Their origin and locations are not yet fully known, but they could play a major role in ocean transport processes. (After McDowell)

particles. The rate at which particles are formed, then sink, and in some instances dissolve at depth greatly affects the composition and chemistry of seawater and of sediment on the ocean bottom.

Attempts to assess the vertical flux by collecting and filtering seawater fail because of the rarity of large particles; for this reason, sediment traps have been developed. These traps are set with an open mouth upwards and are deployed for periods of days to weeks to collect enough numbers for measurement. Unfortunately, variations in design have raised questions about whether or not they all collect the same particles and give a representative measure of the vertical flux. Thus a sediment trap intercomparison experiment (STIE) was designed to compare trap performance under real and nearly identical conditions. It was coordinated by Derek Spencer from the Woods Hole Oceanographic Institution in Massachusetts and involved 8 institutions and 28 investigators.

From July to November 1979, 21 sediment traps of 6 different designs were deployed at depths from 600 to 3,800 meters in the Panama Basin. This site was selected because of very high surface biological productivity and the likelihood of large vertical fluxes, which would allow small traps to recover significant amounts of sample. The traps varied from small cylinders, only a few centimeters in diameter, to large cones with honeycomb baffles that had openings of up to one meter or so.

To minimize the effects of spatial variability, traps of different design were placed at the same depths on five different moorings spaced as close together as possible. Temporal effects were examined by putting floating traps in the near surface waters for short periods during the deployment and recovery cruises. Two of the moored sediment traps were designed to collect a sequence of samples.

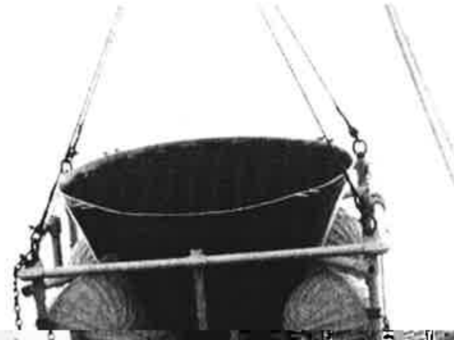
Results of the STIE program showed that in spite of large temporal variations, the four-month average fluxes measured by different traps collecting over a gram of material fell within a 15 percent range. Time-series traps indicated that throughout the deployment period of four months, the vertical fluxes varied by more than an order of magnitude. These traps covered the full range of size and shape of those deployed. The floating sediment traps showed a great difference in the daytime and nighttime fluxes from the upper 300 meters of the water column. However, their average was quite consistent with the moored traps at 600 meters. In addition, current meters deployed during the experiment showed that the times of the major changes in the vertical fluxes, as recorded by time-series sampling traps, coincided with the direction of the mean current.

The total mass vertical flux and the flux of clay particles increased with depth. This finding is consistent with several other recent sediment trap findings and indicates that there is an important horizontal component contributing to the vertical flux. At this time it is not fully understood how this occurs. The simplest explanation is that sediment eroded from the ocean boundaries is transported horizontally as fine particles by rapid advective and diffusive processes and is then aggregated to form particles that settle more rapidly.

The vertical fluxes recorded in the deep water are consistent with the known rates of sedimentation in the Panama Basin. This same observation has been shown in other sediment trap experiments. Thus the STIE data, serving to substantiate earlier sediment trap data, are providing a vastly improved picture of the way particle-transport processes operate in the ocean.

A Changing View of Marine Food Chains

The 1.37 billion cubic kilometers of ocean water is the site of intense biochemical activity carried out by organisms that span a tremendous size range—from picoplankton (less than 2 microns in their largest dimension) and the slightly larger nanoplankton



Sediment traps. The photo at the left shows parts of a floating trap that catches ocean particles over a wide path and at varying depths. At right is a larger, cone-shaped trap; these and other designs were used in a comparative experiment in the Panama Basin. Sediment traps, which can also be moored, help oceanographers understand the rate at which particles form, sink, or dissolve. Scientists then know more about the composition and chemistry of seawater and sediment on the ocean bottom.

to the great whales (greater than 20 meters). Intriguing evidence, gathered over the past decade, suggests [illegible] face of very small organisms in the dynamics of marine food chains. Oceanographers had realized for a long time that towed nets created an inherent size bias in the samples collected and did not provide an adequate picture of energy cycling in the oceans. However, nano- and picoplankton were not considered to be critical in the overall scheme of marine energy and biomass fluxes until recently.

This changing view of marine food chains comes from technologies that allow the oceanographer to study quantitatively, for the first time, consumption and production rates of organisms too small or too delicate for standard methods of investigation. With these new technologies, however, it is now apparent that most marine energy and chemical cycling takes place in the nano- and picoplankton by organisms

Two technological developments now permit [illegible] biochemical rate processes in that minute [illegible] the ability to grow oceanic species of nanoplankton in culture. Chemical oceanographers, while developing methods to assay trace metals, have found that new "clean" techniques for isolation and growth were necessary to prevent contamination and toxicity by trace amounts of metals. Recently, NSF-funded phycologists have applied ultraclean techniques with tremendous success in culturing and studying the metabolism of the delicate oceanic species of nanoplankton.

The second development is the application of a variety of fluorescent microscopy techniques in identifying and quantifying nanoplankton in field samples. Such techniques use autofluorescence of photosynthetic pigments, vital strains that discriminate between living and dead cells, and fluorescent antibodies that bind only to specific species of nanoalgae and bacteria. Although the cells may be too small to be identified or even distinguished from detritus with a light microscope, the fluorescence of the stain can be easily and unequivocally seen and measured.

Some workers are using these techniques to examine and enumerate mixed-species field samples [illegible] nanoplankton producers in the context of energy-cycling studies. Others have found that the nanoplankton also contains a rich fauna of microconsumers that are the same size as the microproducers, and they have begun an investigation of consumption rates.

Current research is also beginning to establish the connections between energy flux of nanoplankton and much larger oceanic organisms. For example, salp populations, frequently a dominant component of the oceanic gelatinous zooplankton, may depend on nanoplankton for food. This realization is based on studies using direct observation of the gelatinous plankton by scuba divers, instead of net sampling. Scuba techniques and shipboard feeding experiments are become progressively more sophisticated.

Freed of the limitations of net sampling and equipped with a range of new technologies, oceanographers will be able to identify the important links in the total marine energy and biogeochemical chains. In the future, the field will see increased use of automated quantification techniques, improved ability to culture important organisms, and greater use of *in-situ* observation and experimentation.

Hydraulic Piston Coring

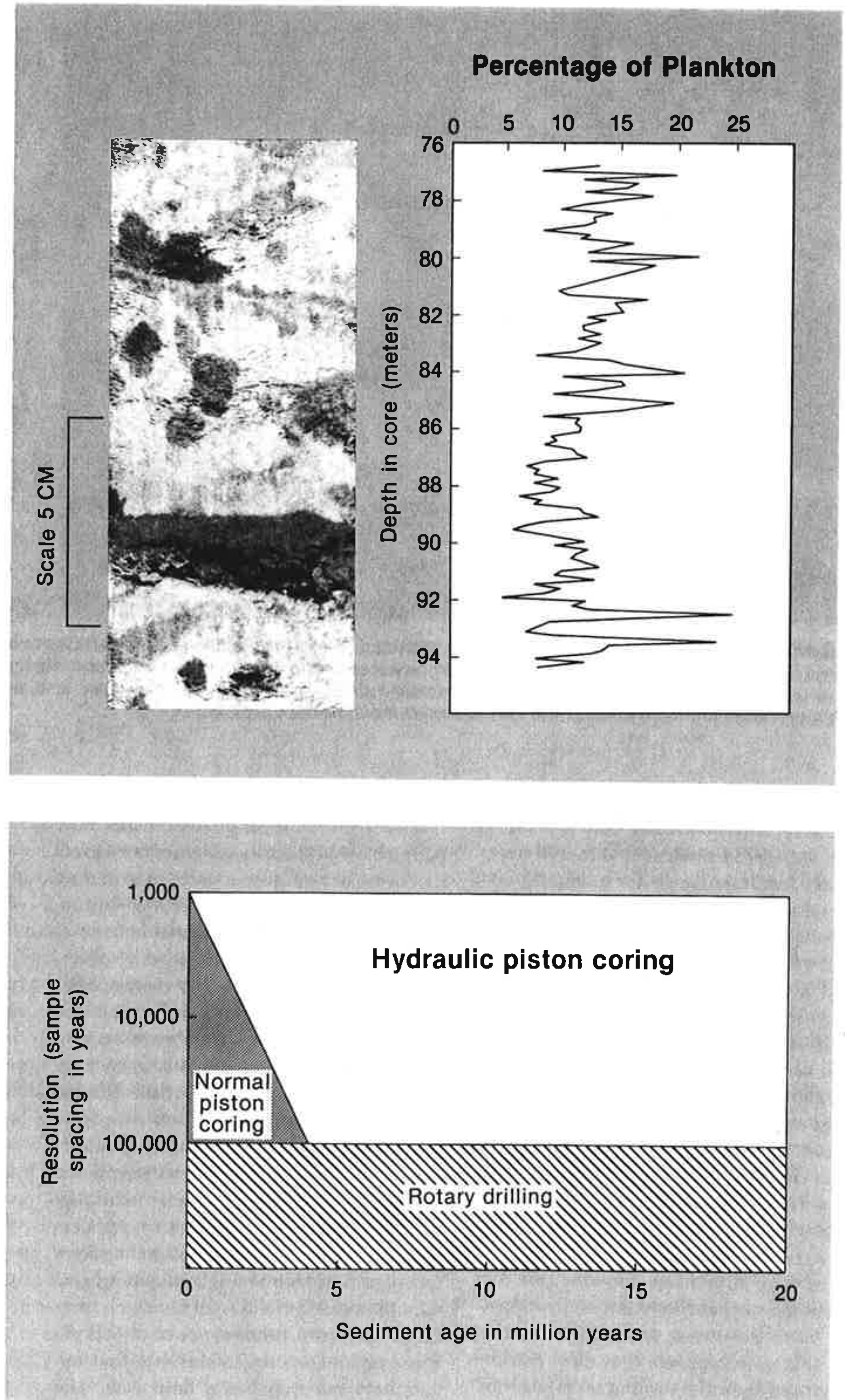
The recent advent of a technique for making long, continuous, undisturbed sediment cores in the deep sea has created a new array of opportunities for high-resolution studies of older oceanic sediments. This technique—the hydraulic piston corer (HPC)—can recover sediment cores hundreds of meters long and spanning tens of millions of years, yet with the original layering preserved intact. It avoids disturbances normally caused by rotary drilling and retrieves the kind of high-resolution records previously obtainable only from conventional piston cores 10 meters or so in length.

As a result, climatic signals in HPC cores can be analyzed at the closest sample spacing possible in deep-sea sediments: several centimeters, equivalent to time steps of a few thousand years. This new technology has already had a major impact on work requiring detailed resolution. For example, studies of long-term climatic change based on geological, chemical, and biological signals in HPC cores have been done.

The earth's climatic system is basically a heat engine that receives energy from incoming solar radiation and redistributes it from the equator to the poles in the oceanic and atmospheric flow. This redistribution now occurs within a specific set of boundary conditions represented by the earth's present physiographic configuration, including the shape of the ocean basins and the heights of major mountain belts. Any major differences in these boundary conditions in the past due to tectonic changes are likely to have forced a different pattern of global heat redistribution, involving changes in oceanic or atmospheric circulation.

Of particular interest to oceanographers are the narrow shallow passageways that link ocean basins to one another or to marginal seas. These passageways critically control the exchange of surface and deep waters, and they are highly vulnerable to enlargement or closure by small-scale tectonic movements.

One of the most dramatic changes was the final closure of a former seaway through Central America by the emerging Panama Isthmus some three million years ago. This was accompanied by several changes recorded in HPC cores. Nick Shackleton

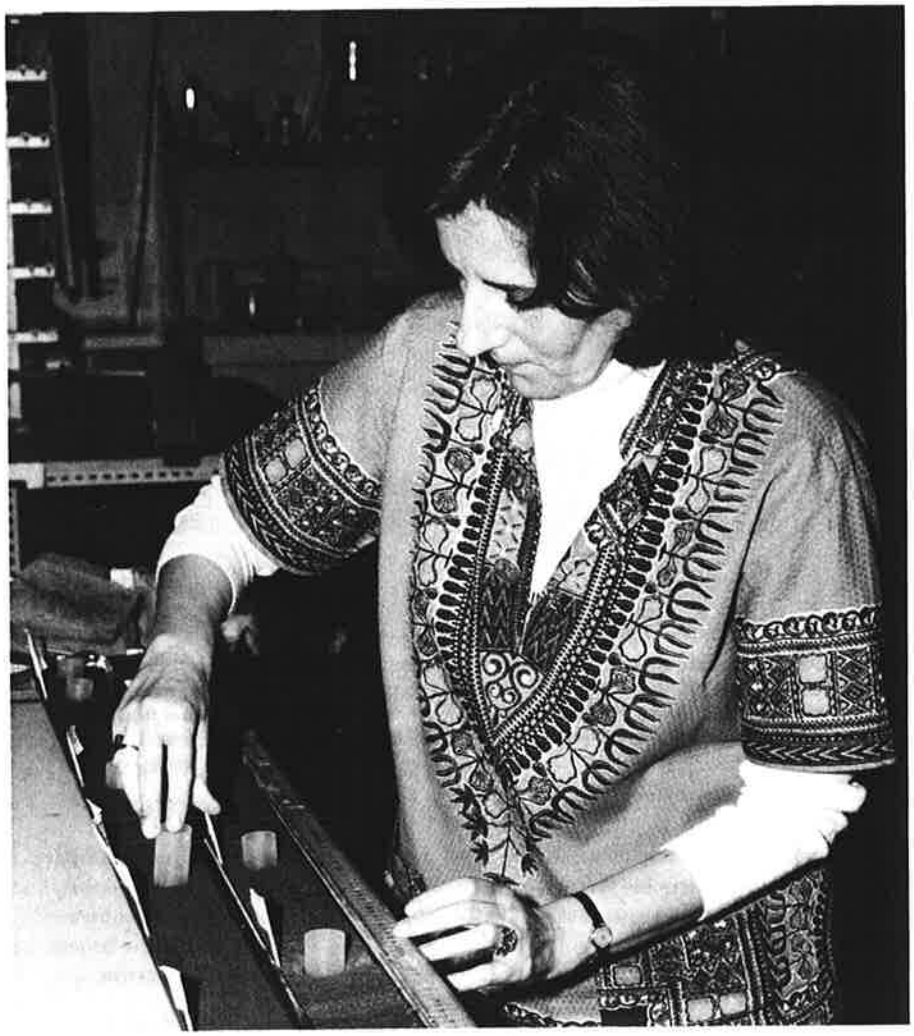


A new technique. Hydraulic piston coring is revolutionizing ocean sciences. As shown in the diagram at the bottom, piston cores of the sea floor retrieve short, detailed records. Rotary drilling yields long records, but detailed fluctuations are lost to drilling disturbances. By comparison, the hydraulic cores obtain long, continuous, and undisturbed geological records, such as those showing original layers and burrows (top left). The cores also show large variations in the proportion of marine plankton shells, compared to inorganic muds from the continents (top right). These variations exhibit major changes in rhythm over time.

of Cambridge University found that chemical (stable isotope) indicators of global ice volume began to show stronger fluctuations about three million years ago, reflecting the first establishment of substantial ice sheets in the Northern Hemisphere.

Warren Prell of Brown University and James Gardner of the United States Geological Survey also found a significant difference in the rhythm of sedimentary deposition before and after this time. They analyzed variations in the proportion of sand-sized skeletons of marine plankton relative to fine inorganic mud weathered from the continents. For sediments of the past half-million years, this measure shows very large cycles about 100,000 years long, and this rhythm matches the most prominent cycle in the stable-isotopic record of global ice volume. Earlier than three million years ago, however, there is no obvious 100,000-year cycle of sand-sized plankton in the HPC records.

These results suggest that the climatic response of the ocean-atmosphere system has evolved because of geotectonic changes. Determining the evolution of this response toward the modern state will contribute significantly to the emergence of a unified theory of climatic change on earth.



Core samples. A geochemist with the Scripps Institution of Oceanography inspects samples brought up by the hydraulic piston corer in the Gulf of California. Cores recovered there and in the Atlantic and Caribbean hold a wealth of new knowledge for such disciplines as paleoceanography, paleoclimatology, sedimentology, and organic geochemistry.

Oceanographic Facilities and Support

General-purpose surface ships continue to be the primary facilities required by most oceanographers. In 1981 NSF supported about 70 percent of the operations of a 25-vessel academic fleet, plus the submersible *Alvin* and its tender *Lulu*. This fleet is operated by the 16 member institutions of the University-National Oceanographic Laboratory System (UNOLS), which oversees scheduling and coordination. The fleet supports federally sponsored basic and applied research projects by academic institutions throughout the United States.

Investigators from more than 145 separate research programs made use of the academic fleet in 1981. Scientific personnel, including graduate students, spent more than 38,000 days at sea doing ocean research from the arctic ice edge to Antarctica. All aspects of marine science were accommodated, including physical, biological, and chemical oceanography; submarine geology and geophysics; ecology, living and nonliving resources; air-sea interactions; and environmental quality. The daily cost of operating UNOLS vessels ranged from $460 for the smallest nearshore ships to $10,600 for the largest deep-ocean research vessels.

In recent years, sharply rising costs and declining levels of relative support by other agencies have forced reductions in the number of vessels in the academic fleet (from 35 in 1971) and the lay-up of some vessels for extended periods. Efforts to modernize and increase the versatility of the fleet continue. Five replacement ships have been added in the past five years, two of them in 1981. The *Cape Florida* was delivered to the University of Miami in June and the *Cape Hatteras* to the Duke University/University of North Carolina consortium in August. These new 40.5-meter ships, built and owned by NSF, are leased to those universities to replace older and more costly ships.

Scientist and crew reactions to the new ships have been very positive. They represent a five-year effort by NSF and UNOLS to design and build a modern cost-effective ship for coastal oceanography. They offer good sea-keeping characteristics for year-round operations, plus adequate working space and the capacity to handle modern instruments. Yet they are cost effective for short cruises, a necessity for seasonal investigations of coastal processes.

In addition to surface ships and related support facilities, NSF continues to fund the major portion of the operating costs of

New ships in the academic fleet. The *Cape Florida* (left) and *Cape Hatteras* (right) are two new 40-meter research vessels owned by NSF. They entered service in 1981 under the oceanographic facilities support program and are leased to universities in Florida and North Carolina, respectively, for coastal studies. These are the newest members of a 25-vessel fleet; with these surface ships and the submersible *Alvin*, academic institutions all over the country carry out federally sponsored research.

the deep-submergence vehicle *Alvin* and its tender *Lulu*. This submersible system is owned by the U.S. Navy and operated by the Woods Hole Oceanographic Institution as a national facility. Other support derives from the Navy and the National Oceanic and Atmospheric Administration. Requests to use *Alvin* are evaluated by an advisory committee representing a broad spectrum of oceanographic expertise.

Ocean Drilling

New activities in scientific ocean drilling are at a critical stage in their development. To provide the careful attention they need at this time, NSF established in fiscal year 1981 an independent program for scientific ocean drilling. It reports directly to the head of the Foundation and encompasses the agency's deep-sea drilling project and its ocean margin drilling program.

Deep-Sea Drilling Project

This effort to explore the earth's surface beneath the seas is carried out by the research vessel *Glomar Challenger* through drilling and coring expeditions. As of July 1981, 914 holes had been drilled at some 551 different sites during 80 cruises, or legs. Following are project results for fiscal year 1981:

- Rocks and sediments ranging in age from 135 million years B.P. to recent deposits were recovered on leg 77. It began in December 1980 at Fort Lauderdale, Florida, and ended in early February 1981 at San Juan, Puerto Rico. These sedimentary sequences will give important clues to the depositional and structural history of the Gulf of Mexico basin and nearby areas.

- Leg 78A, finished in the spring of 1981, investigated the crustal convergence zone where the edge of the Atlantic Ocean plate is being subducted beneath the Barbados Ridge. Among its most exciting discoveries was a massive fault zone. It separates deep-sea sediments that are being underthrust into the earth's interior from those peeled off within the crustal convergence zone.

- In leg 78B scientists successfully relocated, and installed sophisticated equipment in, a hole drilled to 664 meters by the *Glomar Challenger* in 1975. The site was the west flank of the Mid-Atlantic Ridge; the original purpose of the drill was to study the composition of the oceanic crust.

  The *Challenger* returned to the site in March 1981. Comprehensive measurements showed two ancient reversals of the earth's magnetic field recorded in the crustal rocks.

  Also on this cruise, a seismometer deployed more than 500 meters below the sea floor recorded several earthquakes that occurred on the Mid-Atlantic Ridge. This result shows the feasibility of placing large, unmanned observatories in boreholes in the ocean floor.

- Leg 79, concluded in May 1981, confirmed the existence of a vast field of salt domes on the deep-sea floor off the Atlantic coast of Morocco. This evidence also tends to confirm the fit of the Moroccan margin against the margin of Nova Scotia, where similar salt domes are believed to lie at the foot of the continental slope.

- In legs 80 and 81 cores from the eastern North Atlantic suggest that a submarine promontory called the Goban Spur is part of the European continental land mass. This body of land foundered when the North American continent separated from Europe and Africa; it then subsided to ocean depth.
- Extensive use of the hydraulic piston corer, including the new variable-length corer, recovered an excellent record of the subsidence history of Rockhall Plateau, a foundered sliver of continent left behind when Greenland separated from northern Europe.

Ocean Margin Drilling Program

Based on the *Glomar Challenger*'s global reconnaissance in the deep-sea drilling project, this program was seen as a combined effort by academic, government, and private industry. Together they would support and aid an investigation of the geology and paleoenvironment of the continental margins and ocean crust. Though not a resource assessment project, the new program would help build a geologic framework for future oil and gas exploration.

Early planning began in October 1980, when NSF and a consortium of 10 U.S. oil companies entered into a joint agreement to share planning and financing of the program's first phase.

NSF had planned to convert the government-owned vessel *Glomar Explorer* into a drilling ship for research in currently inaccessible areas, such as icy seas. The *Challenger* could then be retired by 1984, when operations under the new program were to begin. However, in late 1981 members of the consortium decided to withdraw from the drilling project, primarily because no other oil companies could be persuaded to join and share the considerable expenses involved.

At this writing, NSF is examining alternative programs without industrial funding. In addition, the National Academy of Sciences is studying the scientific merit of the project in terms of overall research goals in the geologic sciences—especially as they relate to the marine area. The Academy was to give the United States Congress a final report in July 1982.

South Pole telescope. Five days of continuous observations with an 8-centimeter solar telescope similar to this 20-centimeter one have given a wealth of information on the sun's interior. Among the recent findings: the sun's chemical composition is now known to be the same as that of other stars.

United States Antarctic Research

Situated at the earth's axis of rotation, the South Pole is a superb location for studying the sun. In the summer, the sun circles high overhead for weeks, and the cold, clean, dry atmosphere enables uninterrupted, excellent viewing for days at a time. Compared to the North Pole, which is in a region of drifting sea ice, the South Pole has a stable viewing platform—the antarctic continental ice sheet.

The sun's interior characteristics have been predicted by mathematical modeling, but there are only two ways to test these predictions. One, an exceedingly difficult experiment done in the United States to record solar neutrinos associated with nuclear burning, failed to record the numbers originally expected.

The other method is to detect solar oscillations, or pulsations in the size of the sun, in a manner analogous to terrestrial seismology. Oscillations with periods of about five minutes and amplitudes of tens of meters have been known since 1960 and have provided information on the outer layers. For probing greater depths, longer-period oscillations must be detected and measured over several days. Evidence of 160-minute oscillations was obtained in 1976, but long, continuous measurements were not possible because the observations were made from the midlatitudes. Also, interference caused by the earth's atmosphere and rotation prevented precision sufficient to describe the interior.

In January 1980 at the South Pole, American and French investigators made 120 hours of continuous solar observations of oscillations and visual features, using a spectrophotometer and an 8-centimeter telescope. The following summer, in January 1981, a 20-centimeter solar telescope was added, and American and Swedish workers finished a five-day run of related measurements.

Astronomers think that these observations provided as much information on the sun's interior as did the thousands of years of astronomy that went before. Interference was about one-tenth that of the previous observations, providing a tenfold increase in the precision of the recordings. The five-day length of the continuous recordings means that characteristics of many cycles of even the long-period oscillations were captured in sufficient detail to require substantial changes in earlier ideas about the structure of the solar interior.

Significant preliminary results have come from the first two seasons of observations. The convection zone of the sun—the region between the thin outer layer and the core—has been found to extend to within 0.3 solar radii of the center, compared to 0.86

radii predicted by the prevailing model. Also, the sun's chemical composition is now known to be much the same as that of other stars, whereas an earlier model had predicted a different chemical makeup.

Astronomers are confident that, with data from the South Pole, they can achieve one of the remaining great prizes of solar astronomy: mapping temperature and density throughout the interior of the sun with an accuracy of plus or minus 2 percent.

The solar observations were part of the United States Antarctic Research Program, which last year fielded 77 projects. They were done throughout the continent at four year-round research stations and a number of summer camps, and in the southern ocean aboard icebreakers and research ships. Following are some other research accomplishments during fiscal year 1981.

The research ship *Melville* spent more than 100 days in the eastern Scotia Sea, between South America and Antarctica. There researchers investigated the geophysics of the boundary of the antarctic tectonic plate and did oceanographic and biological studies that emphasized the role of krill (*Euphausia superba*) in the marine ecosystem. North of Elephant Island, researchers found and measured, using acoustical devices, a swarm of krill measuring several square miles in extent and containing an estimated 10 million metric tons—probably the largest school of marine animals ever measured. The *Melville*'s work was part of an international effort to determine the amount of krill in antarctic waters and how much could be harvested without damaging stocks or other parts of the ecosystem.

A core taken from the antarctic continental shelf by investigators aboard the icebreaker *Glacier* yielded sediments that had been deposited in early Cretaceous time (100 to 120 million years ago), before Australia and Antarctica rifted apart. The core contains a diverse and well-preserved pollen assemblage derived from temperate-zone vegetation. Study of this and other cores will clarify the ecological and climatic setting of East Antarctica before and during the breakup of Australia and Antarctica, which took place about 40 million years ago.

An array of seismometers installed on Mount Erebus, an active volcano, has provided information about microearthquakes (magnitudes less than 3) originating on the mountain and elsewhere. Because Antarctica is considered nearly aseismic, these earthquakes are significant in determining the tectonic characteristics of the Ross Sea area. Information also was collected on the magma chamber and the eruptive mechanism of the volcano's lava lake—one of the world's two convecting magma lakes. (The other is in Ethiopia.) The magma lake appears to be a stable feature, with frequent small eruptions, lava flows, and gas explosions—but very little ash.

A meteorite found in Antarctica with evidence of geologically recent igneous activity appears to be the first recorded example of large-scale heating in a young meteorite. The heating is likely to have taken place when the sample was a part of one of the asteroids or inner planets—probably Mars. The meteorite is one of hundreds collected in Antarctica since 1969 by U.S. and Japanese investigators. These samples have given new insights into the composition of extraterrestrial materials.

Ice cores drilled from two locations in Antarctica are shown to have varying concentrations of nitrate ions with depth. Variations in solar activity are hypothesized as the cause, with likely mechanisms being photochemical fixation in the upper atmosphere or ionization by auroral activity or solar flares. The ion variations in the cores correlate well with known changes in solar activity over the past 200 years. Examination of deeper ice cores may someday indicate variations in solar activity over the past half-million years.

A coordinated launching of 7 instrumented rockets and 12 instrumented balloons from Siple Station has given detailed information on the precipitation of electrons from the magnetosphere, stimulated by very low frequency waves. These precipitation events, which occur along magnetic lines that extend from Antarctica through space to eastern Canada, are of great interest to atmospheric physicists studying interactions of the magnetosphere and the ionosphere.

Arctic Research

Scientists finished drilling an ice core to the bottom of the Greenland ice sheet in August 1981. This project was an international effort to increase understanding of present and past climate and to learn more about the dynamics of large ice sheets. The ice sheet, 2,037 meters thick at the drill site in southeastern Greenland, is made of snow and ice that precipitated over a period of approximately 130,000 years. Successive years of precipitation and partial summer melting compressed the snow into annual layers of ice. Glaciologists can study these layers to learn what conditions prevailed when the snow fell.

Investigators from Denmark, Switzerland, and the United States teamed to do the drilling as part of the Greenland Ice Sheet Program, a five-year series of coordinated projects. Other activities:

- Drilling of shallow and intermediate-depth cores at several locations.
- Airborne radio-echo sounding of ice thickness, internal layering, and bedrock topography.
- Determination of ice dynamics by measuring surface accumulation, ablation, and movement.
- Other geophysical measurements to determine mass balance (whether the ice is growing or shrinking) and flow characteristics.

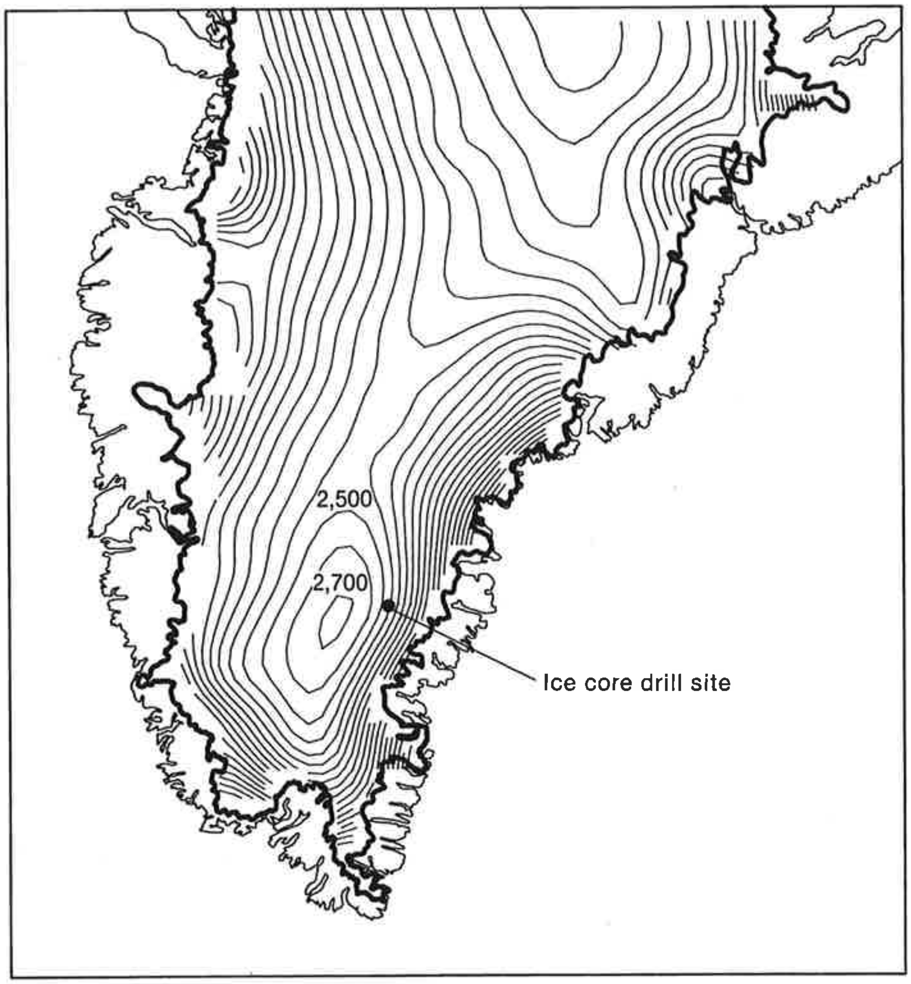
The ice core is only the third ever drilled to the bottom of an ice sheet. The other two were done at Camp Century, in northwestern Greenland (1,380 meters, completed in 1966), and at Byrd Station, Antarctica (2,164 meters, completed in 1968). Study of the earlier cores yielded valuable information on climates and atmospheric constituents that existed for more than a thousand centuries.

The new core will contribute to these climatic studies and enable correlations to help validate the earlier results. Danish scientists are measuring the ratio of pairs of stable isotopes (oxygen-16 and oxygen-18), the Swiss are investigating electrical conductivity and carbon dioxide content, and U.S. researchers are investigating various physical, chemical, and mechanical properties of the core. Measurements of density, the pressure of entrained air bubbles, microparticle content, electrical conductivity, and chemical content were made at the drill site as the core was brought up. This was done to avoid slight changes that take place as the ice core adjusts to a pressure of one atmosphere (at depth the pressure is more than 100 atmospheres).

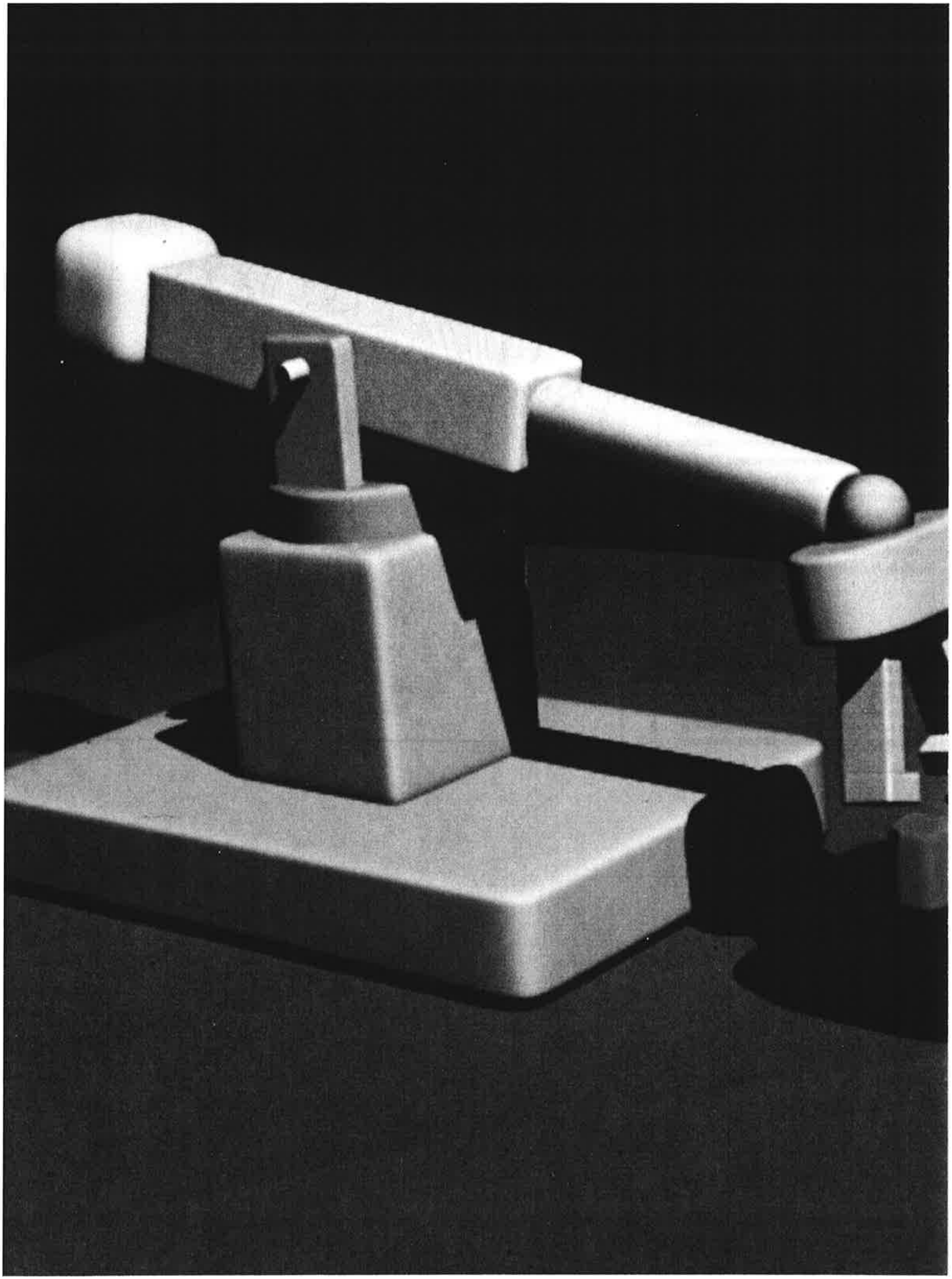
Other U.S. investigations performed as a part of the Greenland Ice Sheet Program include a study of the flow of ice from the drill site toward the coast, which is improving interpretation of the climatic record in the cores. This work involves precise determination of ice movement using satellite positioning. In addition, a computer-based model is being developed to provide surface elevation, bedrock topography, flowlines, longitudinal strain rates, ice velocities, and basal temperatures.

To fulfill a major objective of the program, climatic scenarios for the present and the past are being constructed. These lead to the possibility of predicting climate, based on observation of physical trends in the Greenland ice sheet.

Remaining portions of the ice core are stored at the State University of New York at Buffalo for use by investigators.



Greenland ice core. This contour map shows ice-surface elevations in southeastern Greenland, where a core (only the third of its kind) was drilled to the bottom of an ice sheet 2,037 meters thick. This international project added to understanding of present and past climate.



Scientific, Technological, and International Affairs

5

These NSF programs address complex questions on the economy, industrial innovation, and the national and international effects of science and technology. In doing so, they give decision makers key information; support research on science, technology, and public policy; link the producers and users of research; and contribute to international scientific cooperation.

In 1981, NSF sharpened its focus on industrial science and technological innovation by drawing together programs for industry/university cooperative research, small-business innovation, university-based innovation centers, and innovation processes. Collectively, these programs increase the Foundation's ability to address issues frequently raised by Congress, industry, and the science and technology policy community.

Intergovernmental and public-service activities link the Foundation and the scientific/technical community to state and local governments, the private sector, and the general public. Programs in intergovernmental science and technology, science for citizens, ethics and values in science and technology, and appropriate technology help make scientific and technical resources part of state and local government activities. They also contribute to better discussion and resolution of scientific issues. By participating in these kinds of projects, scientists and engineers help citizens understand the social and ethical dilemmas in technological decision making.

International cooperative activities strengthen science and engineering in the United States by promoting international sharing of research expertise, resources, special facilities, and sites. U.S. scientists are helped through cooperative research projects, seminars, and workshops and through bilateral programs, joint commissions, and informal arrangements for cooperation. These efforts promote mutually beneficial exchanges between U.S. scientists and their counterparts in both developed and developing regions.

Policy research and analysis is a tool to examine the impact of research on industrial development and the nation's general welfare. Areas addressed in both short- and long-term studies include the socioeconomic effects of science and technology; technology assessment and risk analysis; relationships among S&T policies; and the scientific and technological aspects of national environmental, energy, and mineral resource issues.

Through its science resources studies, NSF supports both recurring surveys and studies and special analyses. These give information on science and engineering personnel and funding for research and development. Decision makers can thus get key information on general trends in the U.S. scientific enterprise.

Industrial Science and Technological Innovation

This program has three goals: to expand the knowledge base needed to accelerate technological innovation in the United States; to link the producers of that knowledge with users in the industrial sector; and to increase general understanding of innovation processes and the effect of government actions on them.

Table 6
Scientific, Technological, and International Affairs
Fiscal Year 1979, 1980, and 1981

(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Industrial Science and Technological Innovation	*	*	*	*	277	$17.06
Intergovernmental and Public-Service Science and Technology	*	*	*	*	47	2.50**
International Cooperative Scientific Activities	529	$10.60	812	$12.07	282	10.07
Policy Research and Analysis	137	5.46	80	6.09	104	4.41
Science Resources Studies	52	3.07	79	3.45	46	3.10
Information Science and Technology	40	4.43	59	5.08	***	***
Total	**758**	**$23.56**	**1,030**	**$26.69**	**756**	**$37.14**

*Included under Engineering in FY 1979 and FY 1980

**Funds for Science for Citizens and Ethics and Values in Science and Technology (EVIST) came under the Science and Engineering Education appropriation in FY 1981.

***Included under Biological, Behavioral, and Social Sciences in FY 1981

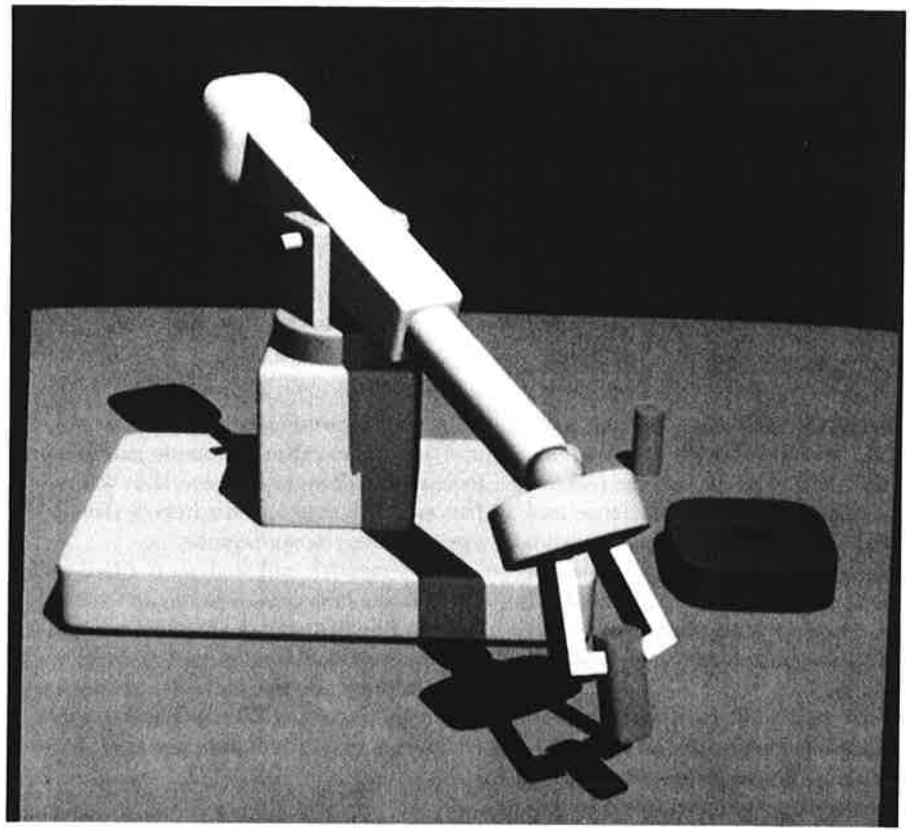
SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

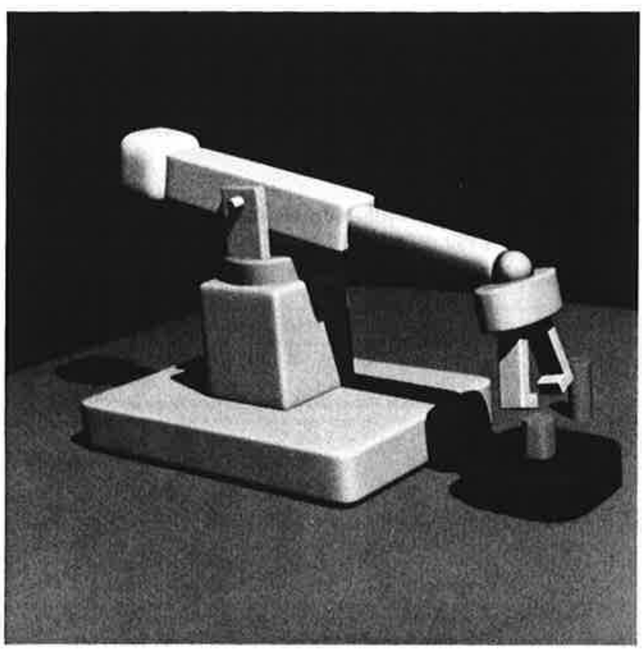
The program has four major activities: industry/university cooperative research projects, small-business innovation research, university/industry cooperative research centers, and innovation processes research. Projects under two of these are described here.

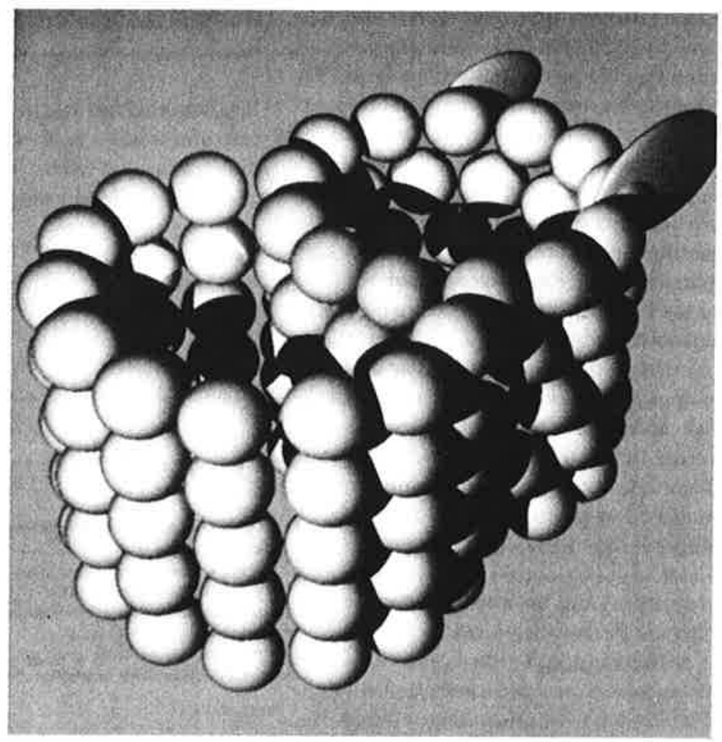
Industry/University Cooperative Research Centers

These centers stimulate the adoption and use of university research results by industry and foster long-term collaboration between universities and industry. Together with a group of industrial firms, NSF helps organize and cofunds interdisciplinary university research that is compatible with university objectives and responsive to industry needs. As the research program and industry acceptance grow, the centers mature and NSF phases out its support.

With a planning grant from NSF, Ohio State University developed a plan for a welding research center. Eight companies—IBM, General Electric, General Motors, Standard Oil of Ohio, Caterpillar Tractor, Bishopric Products, GATX, and Westing-







Computer graphics. These computer-generated pictures were done with a technique called super-quadrics ray tracing. It produces high-quality, smoothly contoured and shaded solid configurations in full color. The realistic displays can simulate movement; as seen here, a robot arm lifts a solid object and puts it in a receptacle. Other shapes can also be simulated, including the molecular structure shown. This is another example of the work done by industry-university cooperative research centers—in this case, the Center for Interactive Computer Graphics at Rensselaer Polytechnic Institute.

house—agreed to cofund the center with NSF. The Center for Welding Research at Ohio State University started operations in 1980.

In one year, the budget for the center grew from $500,000 to $690,000, with industry providing 60 percent of the support for the second year. Euclid, John Deere, and TRW joined the original participants, and industrial support is expected to continue to grow, allowing NSF to phase out its funding in the fifth year.

The center operates as an autonomous entity within the university, reporting to the dean of engineering. It has an industrial advisory board composed of a representative from each member company.

The center's research program currently consists of these major projects:

- A study to develop methods for sensing variables in arc-welding processes. The center's largest project, it has potential application to automatic feedback control. Proper process feedback control allows for adaptive weld control and the implementation of automatic and robotic arc-welding systems in welding fabrication.
- An investigation of weld pool solidification under time-dependent power variations. It involves pulsed power sources for welding, where the source is alternated between a high and low power level.
- Laser and laser-arc studies, focusing on the interactions of laser light and a gas tungsten arc during welding and the effects of laser plume generation on weld penetration.
- A study of the weld strength of steel structures under mixed loading conditions. The study is investigating the strength of fillet welds under mixed loading conditions and the effects of weld deficiencies on the weld strength. This three-year study will involve the development of computer programs and experimental stress-analysis techniques for establishing failure criteria for commercial welds.
- An analysis of welding discontinuity, including its causes and effects.
- A new study focusing on resistance welding defects and how to control them.

One of the effects of starting this center has been the general upgrading of the university's welding laboratory facilities, particularly the large number of major equipment acquisitions. The center's formation helped secure, at no cost to the university, a robot welder from Cincinnati Milacron; a large pulsed welder for the laboratory came from the Dimetrics Company. The university purchased a helium-neon 5-kilowatt laser for the center and also installed a computer facility to strengthen the center's research activities. Other major acquisitions include a high-speed oscilloscope/logic analyzer, fiber optic weld monitor, three-axis weld manipulator control, computerized vision system, photoelastic reflection polariscope, high-temperature sensing system, and an optical bench.

Small Business Innovation Research

This program supports advanced research in small high-technology firms and stimulates follow-on private capital to increase technological innovation and the public return on investment from NSF-supported research. The program involves an annual solicitation of proposals from science-and technology-based firms having 500 or fewer employees. Research topics are those where successful results could lead to industrial application and significant public benefit. Government funds are spent solely on research consistent with Foundation objectives; private funds pursue any commercial applications of the research.

The program involves three phases on a highly competitive basis. One out of eight to nine proposals received has been supported in the first phase, and half or less than half of these are funded in the second phase. The proposing company is encouraged to get a commitment for the third phase of funding from a third party, such as a venture-capital or large industrial firm. Use of the third party not only assures objectivity as to potential commercial application but often provides an indirect evaluation of the potential market, the small firm's management ability, and future financial requirements. All of these are important to the technological innovation process.

Under the first solicitation in 1977, the first two phases are complete and the third one has begun. Examples of work supported are as follows:

- OMEX, a small California firm, was funded to do laser optics research. As a result, the firm attracted $5 million of follow-on venture capital from a small-business investment company. OMEX was then able to pursue large-scale computer storage applications. This in turn led to a $4 million contract to produce electronic filing hardware for a large West Coast title insurance company. Electronic filing may be a major new field of technological innovation.
- In 1977, before a Supreme Court decision on proprietary rights to genetic inventions and the resulting availability of venture capital, NSF funded a proposal from Collaborative Research in Massachusetts for the enhancement of animal protein production by genetic technology. The NSF-funded research led to $13 million of follow-on funding to the company, primarily by a major U.S. chemical firm.
- Terra Tek, a small company in Utah, received support for research on metal fracture toughness. The company applied the research results by developing an instrument to measure the metal fracture toughness of drilling bits used in mining and petroleum work. The instrument is now used worldwide, and the product line is being expanded to meet a wide range of metal fracture toughness problems.
- Soil and Land Use Technology of Maryland received NSF support for research on the feasibility of introducing into the U.S. foreign food crops that are adapted to environmental stress, such as arid, wet, saline, or cold climates. This comprehensive study of hundreds of trees, shrubs, and plants has become widely known in the United States and abroad. The company has received $130,000 of follow-on funding from the American Newspaper Publishers Association to investigate kenaf, a hemplike crop that grows in wet areas, as a possible source of newsprint. Other crops identified by the study are being considered for follow-on investment.

The program also encourages the coupling of small, high-technology firms to university resources. Most of the grantees use university scientists and engineers as consultants, both in the United States and sometimes abroad. Some also have subcontract and facilities-use arrangements with universities.

More than 280 awards have been made from the 2,000 proposals received. The program also has served as a model for a similar program in the Department of Defense and for legislation on its possible application in other federal agencies.

Intergovernmental and Public-Service Science and Technology

This NSF activity consists of the following programs: intergovernmental science and technology, science for citizens, ethics and values in science and technology, and appropriate technology. They are meant to have a combined impact and to do the following:

- Aid the integration of scientific and technical resources into state and local government activities.
- Develop new and improved community-based approaches to discuss and resolve science and technology policy issues.
- Encourage the participation of scientists and engineers in activities aimed at increasing public understanding and helping to resolve policy issues that have significant scientific and technological aspects.
- Identify, analyze, and help resolve the ethical and social dilemmas arising in and from the work of scientists and engineers.

Intergovernmental programs help state and local governments investigate alternative approaches to integrate scientific and technical resources into policy formulation, administrative management, and program activities. Through projects in individual jurisdictions, national public-interest associations, and networks of local governments, NSF support helps state and local governments resolve issues, address problems, and carry out federal policies and programs. It does so by drawing upon the nation's scientific and technical resources, particularly those developed with federal support.

The intergovernmental program has four major activities: a local government program; a state executive program; a state legislative program; and a science and technology resources program.

The local government program supports regional and national innovation networks to promote cooperation in solving common problems with scientific and technical content. This program strengthens the ability of local governments to identify needs and ensure that research is targeted appropriately.

The executive and legislative-branch programs strengthen the policy-making capabilities of governors and legislatures in scientific and technological areas by allowing them to test new approaches to decision making and improve existing ones. Several projects begun with NSF funds have been integrated into legislatures or gubernatorial offices, which have assumed the full costs of continuation.

A key element of the science and technology resources program is the Federal Laboratory Consortium for Technology Transfer. With more than 200 member laboratories, the consortium helps identify and give access to existing resources for solutions to public and private-sector problems.

The science for citizens program encourages new and better ways to provide scientific and technical information and expertise to citizens, and to their organizations and representatives, so they can better understand and participate in decisions on policy issues. The program supports forums and workshops dealing with a wide variety of science-related issues in communities around the country. It also backs local and regional public-service science centers that are meant to become self-sustaining eventually.

The ethics and values in science and technology (EVIST) program supports research and discussion on ethical aspects of contemporary issues in science, technology, and clinical research. It also supports inquiries into the social processes that influence the conduct of scientists, engineers, and medical researchers in such diverse areas as agriculture, computer systems development, occupational health, and research on chronic diseases. There is close collaboration between the EVIST program and the National Endowment for the Humanities in these efforts.

In the fall of 1979, Irwin Feller at the Pennsylvania State University began a detailed assessment of the state legislative program, an NSF intergovernmental activity. As the first major review of the "single-state" strategy of working within the administrative and policy organizations of state government, the Feller report should be particularly useful to other states seeking to develop similar efforts. Its principal findings suggest that the program has helped develop a capacity to use scientific or technical resources in state policy development. The report also indicates that informal relationships and support networks are more important than previously thought in promoting the use of scientific and technical knowledge.

International Cooperative Scientific Activities

NSF research grants often provide opportunities for American researchers to benefit from international contacts during the course of their projects. In addition, formal bilateral agreements and other arrangements for international scientific cooperation permit more intense and selective collaboration between American and foreign scientists. These arrangements between the United States and other countries call for each government to pay the costs of their scientists' participation. Projects under these agreements involve joint planning and often joint access to special facilities, as well as the shared benefits of joint participation.

In many countries international scientific cooperation has recently come under tighter government controls because of increasing travel costs and because international scientific exchange is seen as a significant element in foreign relations. Increasingly, NSF finds it necessary to support scientific and technological cooperative projects through formal understandings. These agreements usually span all the scientific subjects that are supported in NSF's domestic research programs.

Under cooperative science programs with about 30 partner countries, funds pay for U.S. scientists' participation in cooperative research, seminars, workshops, and scientific visits. Exceptions are in the programs with India and Pakistan, where the expenses of *both* sides are mainly borne by U.S.-owned special foreign currency held for use in those countries.

NSF's partner countries in cooperative programs fall into three groups: (1) the industrial, market-economy countries of western Europe, East Asia, and Oceania; (2) China, the U.S.S.R., and socialist industrial countries of eastern Europe; and (3) the less industrial, less developed countries of Africa, Asia, and Latin America.

Special benefits come from international scientific cooperation when scientists of two or more countries jointly work on a regional or global problem. Scientists bring to that problem their own backgrounds and indigenous methodology, and each country benefits from the experience of others. Among the global problem areas where joint basic research is significant are water resources, human migration, and health.

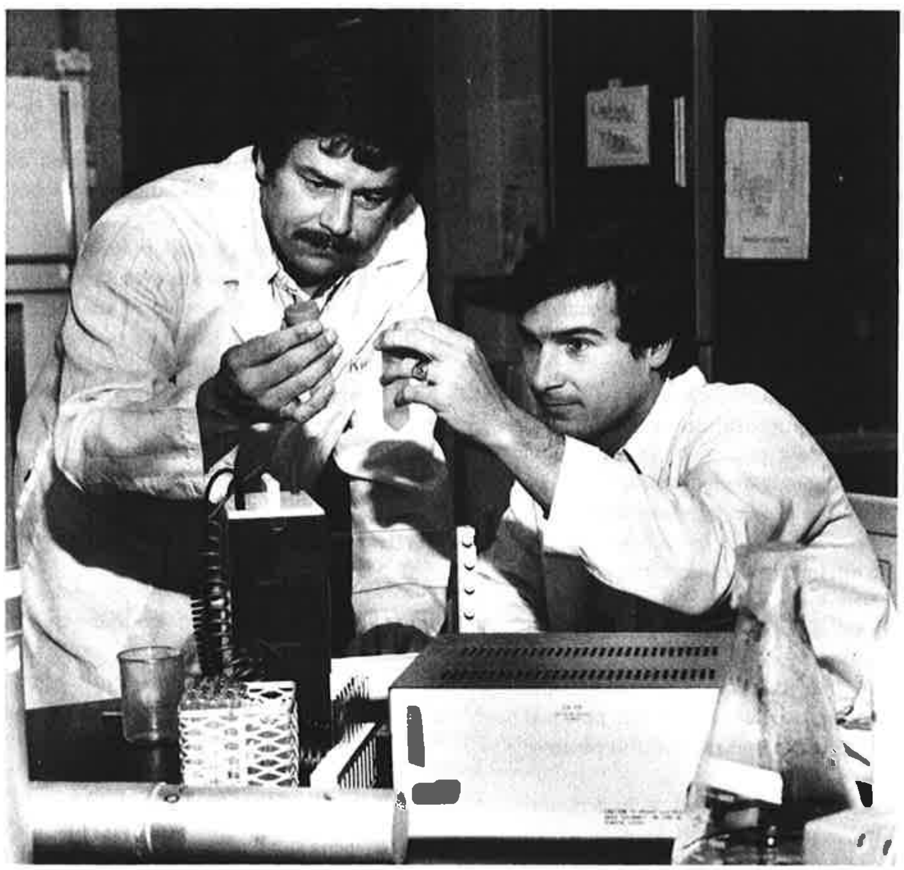
The management of water resources—often involving the carefully planned use of scarce water, the management of excess water where its presence is harmful or dangerous, and the problems of waste-water disposal—has generated several cooperative efforts. In the U.S.-China program, scientists at the University of Michigan are working with colleagues in Qinghua University to compare and improve systems-analysis methods for managing waste water in different social settings. The U.S.-Mexico program recently supported a seminar on cooperative research needs for the renovation and reuse of municipal waste water in agricultural and industrial systems. It was jointly organized by Michigan State University and the Agency for Environmental Protection and Regulation of Mexico.

The relationship of the mining industry to ground water—the influence of water on mines and the effects of mining on ground water—has been the subject of cooperation between the University of Arizona and the Hungarian Mining Research Institute, under the U.S.-Hungary program. And the evaluation of water resources for small-scale hydroelectric power plants is the subject of cooperation between the University of Pittsburgh and the Philippine Bureau of Energy Development.

A second area of research on a global problem addresses the migration of human populations. Under an arrangement between the University of Texas at Austin and the Regional Population Center of Bogota, U.S. and Colombian researchers are developing models for simulation analysis of the effects of migrations on employment and unemployment, economic growth, income distribution, and regional disparity.

In the U.S.-Mexico program, the University of Arizona and the National Institute of Anthropology and History of Mexico recently completed a comprehensive overview of trends in migration within Mexico and the United States, including analyses of economic changes. Like the U.S.-Colombian study, this one featured a computer simulation model. It is expected to be of great interest to the many countries where migrations have important effects on the economy.

Basic research data are needed to solve many global health problems; among them are two related to diseases that are serious in warm countries. The University of Alabama at Birmingham is using recombinant DNA techniques to develop virus strains that will eventually be used to make vaccines against hemorrhagic fever, a severe communicable disease in many countries. Cooperation with the National University of La Plata under the U.S.-Argentina pro-



Studying immunity. Chagas's disease, also called American trypanosomiasis, is one of the world's six most serious parasitic diseases—a tropical malady that afflicts millions of people. Under NSF's science in developing countries program, researchers at Wake Forest University and the Andes University in Colombia are analyzing the natural immune reactions that protect mammals from the protozoans causing this disease. This kind of basic knowledge is needed to solve pressing global health problems.

gram has allowed researchers of both nations to use each other's expertise and the special pathogen containment facilities available in Argentina.

Chagas's disease, also called American trypanosomiasis, affects many millions of people worldwide and is regarded as one of the six most serious parasitic diseases. Fundamental research funded under NSF's science in developing countries program involves scientists at Wake Forest University and a young predoctoral researcher from the Andes University in Colombia. The project includes experiments to study the protective immunity of mammals to the protozoans that cause this disease.

The chief cause of infant death in many warm countries is diarrhea caused by toxins of certain colon bacteria. Scientists at New York University and the Paulist School of Medicine in São Paulo, Brazil, are jointly studying the genetics and molecular biology of these bacteria, hoping to learn how they inherit the capacity to produce the toxins. U.S. participation in this project is supported under the U.S.-Brazil program.

Policy Research and Analysis

The focus here is on policy issues that affect the nation's scientific and technical efforts. Contributions include research, analysis, and assessments of the topics described below.

Environment, Energy, and Resources. National concerns about adequate supplies of energy and other natural resources and about maintaining environmental quality are the impetus for scientific, technological, and regulatory programs in many federal agencies. NSF's environment, energy, and resources program supports and conducts policy studies on the relationship between environment, energy, and mineral resource issues and science and technology policies.

Technology Assessment and Risk Analysis. This program supports studies to help decision makers plan for the impact of new technologies, especially those that may require public policy intervention. Technology assessment seeks to identify the indirect, unanticipated, and delayed consequences of technological change. Examining these consequences before full-scale implementation of the technology is an attempt to identify issues that may become the focus of social conflict and political debate, and those that may inhibit positive technological change.

Risk-analysis studies seek to understand how information about risks is used in science and technology decision making. Risk assessment addresses three areas: the use of risk-and-benefit information in the decision making process; public perception of risk; and methodological issues in risk assessment.

Socioeconomic Effects of Science and Technology. This program supports studies that can be used in domestic science and technology policy making and in formulating international economic policy. These studies give federal decision makers sound empirical information on relationships between science and technology, economic performance, and the quality of life; on the effect of government actions on such relationships; and on methods to generate such information.

International economic policy studies, an experimental effort, began in 1981. Their purpose is to support research and analysis that will enlarge the knowledge base for policy decisions about international monetary institutions and international trade.

Economic Effects of Research and Development

Occasionally NSF supports a project involving several studies. One of these is "Market Structure, International Technology Transfer, and the Effects on Productivity of Composition of R&D Expenditures," by Edwin Mansfield at the University of Pennsylvania. It was completed in the spring of 1981. This project has advanced both methodological and substantive knowledge, with findings in these six areas:

- *Effects of the composition of R&D expenditures on productivity increase.* The study suggests a strong relationship between the amount of basic research carried out and the rate of productivity increase, at both the firm and industry levels. In this relationship, basic research may be acting as a proxy for long-term R&D.

- *Changes over time in the composition of industrial R&D expenditures.* For a sample of 119 firms, the proportion of R&D expenditures for basic research declined between 1967 and 1977 in practically every industry. In four-fifths of the industries, there was also a decline in the proportion spent for relatively risky projects. The proportion devoted to relatively long-term projects did not decline appreciably for the sample as a whole, but the share aimed at entirely new products and processes did decline somewhat.

- *Technology transfer to overseas subsidiaries.* In a sample of 65 cases, the mean age of technologies transferred to overseas subsidiaries in developed countries was about 6 years, in developing countries about 10 years. For technologies transferred to subsidiaries in developed countries, those recently transferred (1969-78) were newer at the time of transfer than were those passed on during 1960-68. This was not the case for transfers to non-U.S. firms. The study also found that the mean lag between the transfer and the time a non-U.S. competitor had access to the technology was about four years.

- *Effects of technology transfer by U.S.-based firms on non-U.S. recipients.* Savings to non-U.S. firms from transferred technology were documented and quantified. If the sample of transferring firms is representative, the total annual savings to non-U.S. users and suppliers due to all technology transfer by U.S.-based firms of the sort studied is at least $35 billion a year.

- *Imitation costs and market structure.* The costs and time in imitating 48 product innovations were analyzed. On average, the ratio of the imitation cost to the innovation cost was about 0.65, and the ratio of the imitation time to the innovation time was about 0.70. Some factors related to variation in the cost ratio were uncovered. Also, an industry's concentration seems to be related to imitation costs.

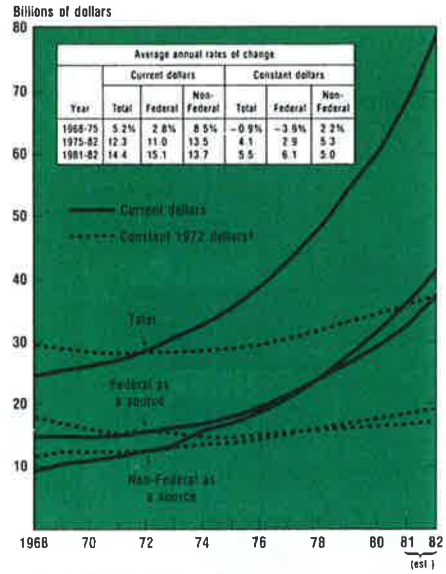
- *Patents and the rate of invention.* Of the same 48 innovations, about half would not have been introduced without patent protection, according to the innovating firms. Excluding drug innovations, the lack of patent protection would have affected less than a fourth of the innovations in the sample.

Commercialization of Energy Technologies

There is an ongoing effort to clarify the federal science and technology role in meeting national energy, environment, and resource goals. As part of that effort, NSF has been coordinating a review of past and future federal policies on the topic of commercializing energy technologies. Listed here are some workshops held in the past year:

- *Mobilizing the private sector to develop fusion energy*—including the integration of ongoing federal activities with present and future private-sector work.
- *The federal role in commercializing active solar heating and cooling technology*—including an assessment of the market potential and the commercial viability of those systems. A similar workshop focused on large-scale windmill technology.
- *The federal role in commercializing magnetohydrodynamics (MHD)*—including a look at institutional barriers and environmental constraints on the use of MHD.
- *Synthetic Fuels Corporation: development strategy and institutional relationships*—appropriate division of responsibilities between the federal energy program, the Synthetic Fuels Corporation, and the private sector; environmental tradeoffs; the implications of alternative federal funding strategies for the future of the synfuel industry.
- *U.S. strategy for international collaboration in fusion energy development*—a look at the costs and benefits of bilateral or international cooperative programs in this area.

National R&D expenditures



[a]Based on GNP implicit price deflator
SOURCE: National Science Foundation

Science Resources Studies

Through this program, NSF surveys, analyzes, and reports on the nation's scientific and technical resources. Publications are sent to a variety of users who develop science policy or allocate science resources in the federal government, state and local governments, educational institutions, and industry. Analysts who study the national and local resource-allocation system for science and technology are another important audience.

During the past year, NSF continued its development of periodic comprehensive national overviews of (1) past and current funding of scientific and technological activities and (2) the supply and use of scientific and technical personnel. Some 30 reports and summaries reported the results of this work.

A key NSF report done under this program was *Science Indicators, 1980*. This fifth volume in a series begun in 1973 gives quantitative indicators of the status of science and technology, accompanied by trend analyses and interpretation. The present volume describes recent advances in science and reports on a major new survey of public attitudes about science and technology.

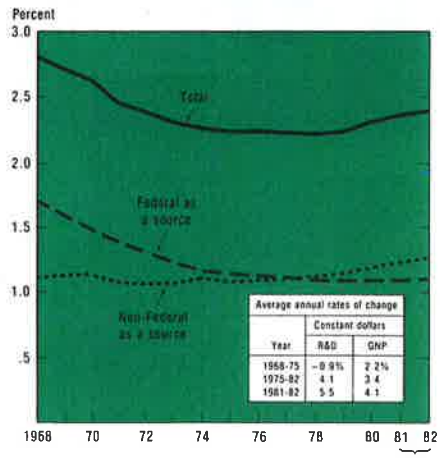
The second volume of a series called *National Patterns of Science and Technology Resources* was published in the summer of 1981. Data in this volume indicate that total U.S. expenditures for research and development will increase in 1982 to almost $80 million. R&D expenditures have increased in real dollar terms each year since 1975, averaging about 4 percent annually through 1982.

The report also shows that national R&D spending as a percentage of the gross national product is expected to reach 2.4 percent in 1982. Between 1973 and 1978 this ratio remained in a range of 2.2 of 2.3 percent; since 1978 it has increased slightly each year.

Also published in 1981 was the first volume in a new series, *Science and Engineering Personnel: A National Overview*, which fills the need for a single, comprehensive overview of scientific and technical personnel. It includes a summary of current supply-and-use patterns for all U.S. scientists and engineers, a detailed examination of the status of doctoral students in those fields, and an analysis of the dynamics of the U.S. scientific and engineering labor market.

Among a number of special studies and analyses during the year was a report on

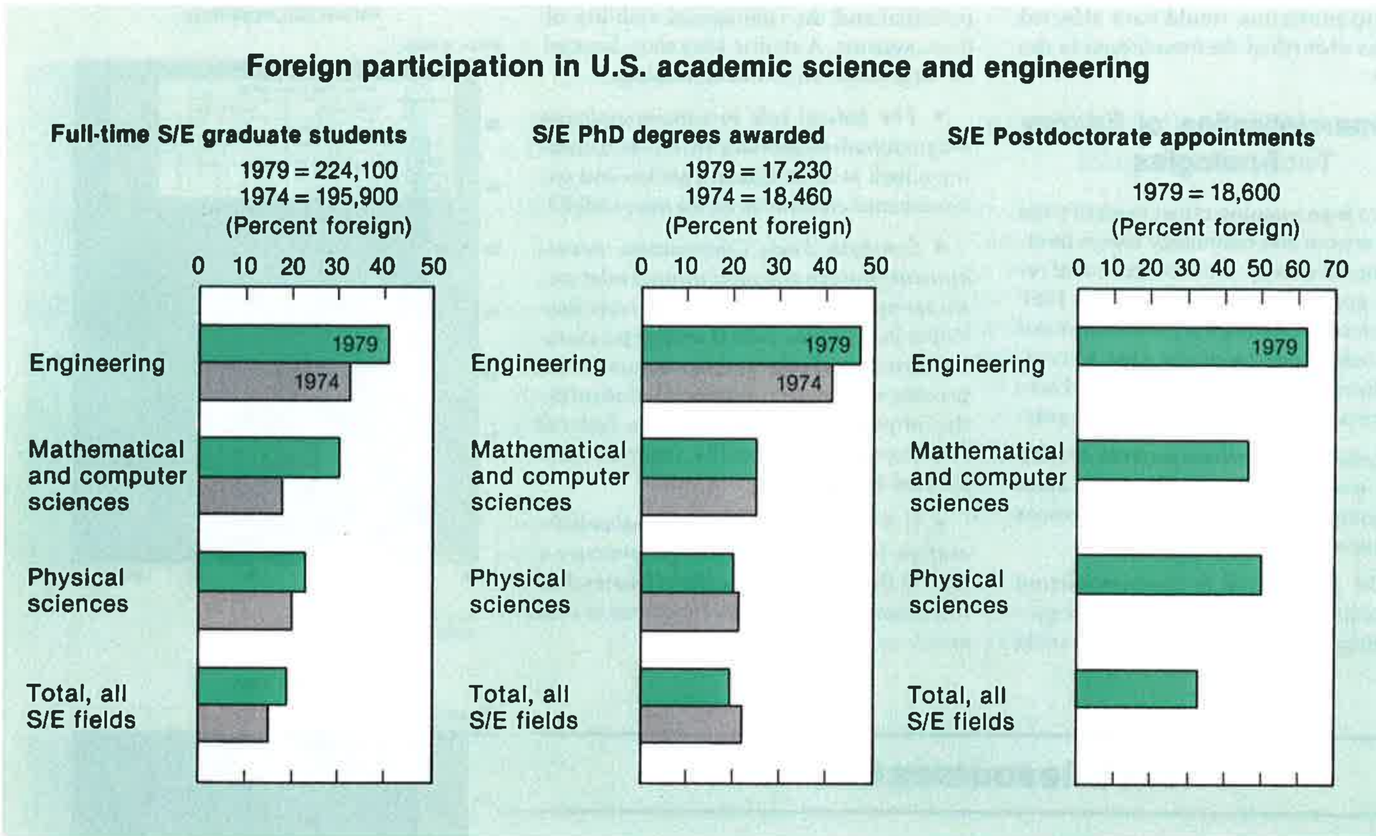
R&D/GNP

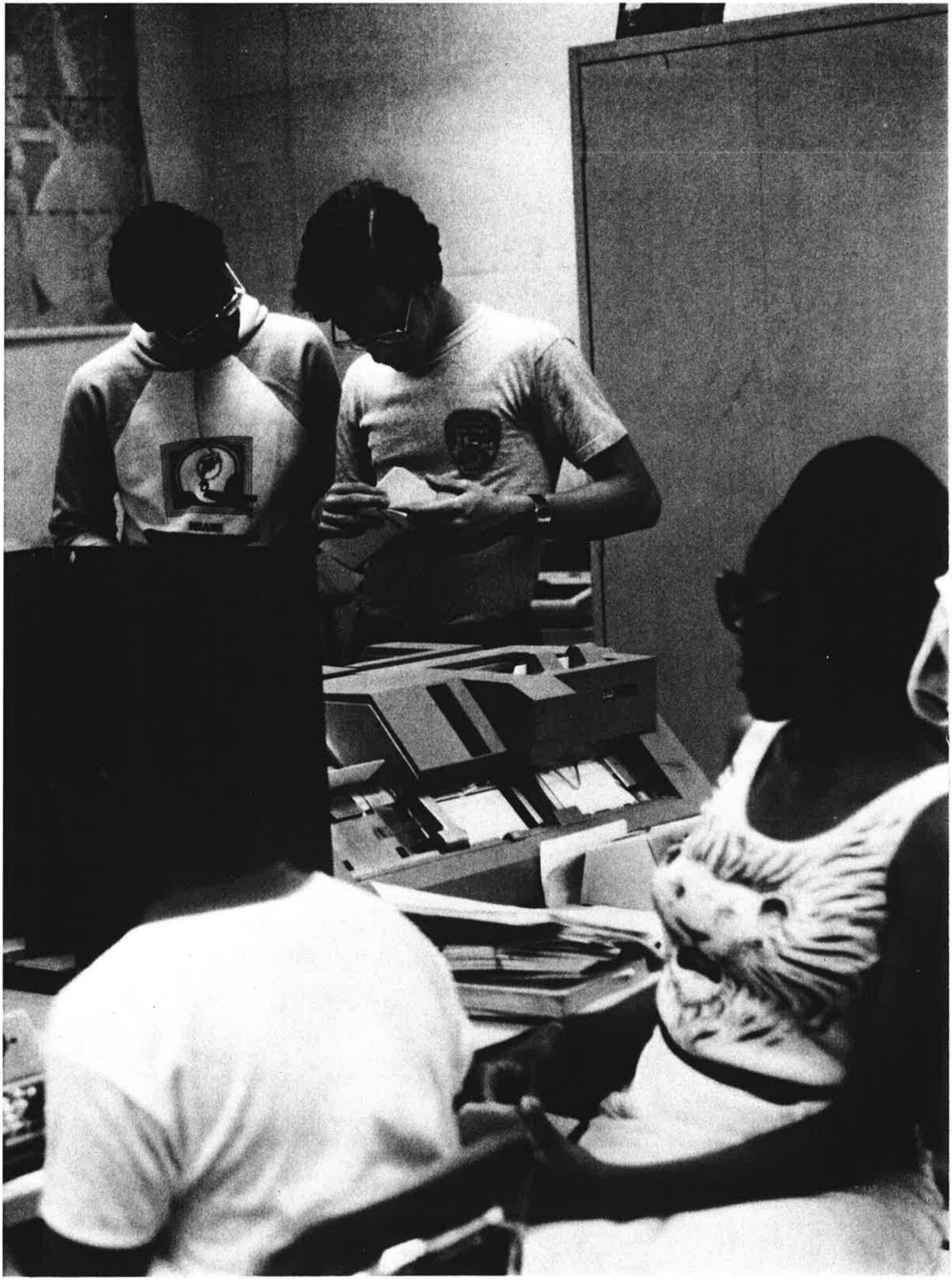


SOURCE: National Science Foundation and U.S. Department of Commerce

the increasing participation of foreigners in U.S. scientific and technical education. This trend has implications for the future with respect to both the demand for scientific and engineering training in U.S. academic institutions and the domestic labor market for those fields.

The impact of this trend is most dramatic in graduate-level engineering, where foreign students constituted more than 40 percent of the enrollment in 1979 and where almost half of the doctorates were awarded to foreign citizens. About a third of these foreign engineering doctorates planned to remain in the U.S. or to pursue doctoral studies after they received their degrees.


Foreign participation in U.S. academic science and engineering
Full-time S/E graduate students
1979 = 224,100
1974 = 195,900
(Percent foreign)
0 10 20 30 40 50
S/E PhD degrees awarded
1979 = 17,230
1974 = 18,460
(Percent foreign)
0 10 20 30 40 50
S/E Postdoctorate appointments
1979 = 18,600
(Percent foreign)
0 10 20 30 40 50 60 70
Engineering
1979
1974
Mathematical and computer sciences
Physical sciences
Total, all S/E fields



Science and Engineering Education 6

NSF has broad responsibility for strengthening science education at all levels and across all fields. Historically, education in the sciences has been regarded as the supply mechanism for the human resources required by the scientific and technological enterprise. NSF has generally emphasized the needs of the academic sector of that enterprise, but in recent years it has also turned its attention to other concerns—for example, the adequacy of the training 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. As a result, 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, two major goals in NSF's science and engineering education program have been: (1) to assure a stable flow of the most talented students into science careers, with particular emphasis on increasing the participation of minorities and women, and (2) to help all citizens increase their basic understanding of science and its contributions to the quality of life.

NSF has supported activities with these objectives:

- To provide high-quality training in science for specially selected students in programs ranging from the secondary school through postdoctoral levels.
- To revitalize subject-matter knowledge of both precollege teachers of science and undergraduate science faculty.
- To improve undergraduate science instruction at two- and four-year colleges and universities.
- To 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.
- To improve the public's understanding of science and its effects on daily life and to inform professional science educators of new developments and methodologies in the sciences and mathematics.

The vignettes that follow show the range of NSF education activities in fiscal year 1981.

Scientific Personnel Improvement

The Foundation's personnel improvement programs support the training of talented scientists in an era of high technology. This assures a continuing input of highly qualified personnel into the nation's pool of scientifically competent persons. Programs that contribute to careers in science and technology include teacher improvement, research participation for students and faculty, and graduate fellowships.

Science-teacher improvement at every educational level is basic to more productivity in a high-technology society. *Research participation* programs encourage high school and undergraduate students to discover and/or develop an interest in

Table 7
Scientific Personnel Improvement
Fiscal Year 1979, 1980, and 1981

(Dollars In Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Faculty Improvement Programs	387	$10.03	406	$11.79	377	$10.18
Minorities, Women, and Physically Handicapped	81	2.36	64	2.23	74	3.48
Student-Oriented Programs	319	5.42	295	5.11	298	5.68
Fellowships and Traineeships	1,744	15.26	1,560	13.96	1,593	14.03
Total	**2,531**	**$33.07**	**2,325**	**$33.09**	**2,342**	**$33.37**

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

science or engineering careers. Firsthand research experience is also highly effective in improving the access of minorities and physically handicapped students to science careers. *Graduate fellowships* support high-ability graduate students for indepth work toward advanced science or engineering degrees.

Faculty Improvement and High Technology

Faculty development supported by NSF at the precollege level helped teachers in grades 5 to 12 give students sound grounding in science and mathematics. This was helpful whether or not the students ultimately became users or practitioners of science. Projects were designed to update or upgrade the knowledge of middle- and high school science teachers. The need here is critical, since half of the teachers involved had not taken a college science course in the past five years and a third did not major in science.

Upgrading activities were designed to give teachers the subject-matter backgrounds they need to prepare science students for high-technology careers or to give them a solid orientation in science. Some examples of course topics are the engineering or technological aspects of solar energy, biotechnology, nuclear power, industrial chemistry, computer science, polymer technology, and industrial economics. In fiscal year 1981, NSF-funded projects helped 12,300 participants improve their teaching of science to an estimated 1.7 million students. The teachers attended either intensive summer workshops lasting up to four weeks or after-hours, academic-year seminars.

Also in fiscal 1981, about 420 participants in three conferences discussed NSF's faculty improvement program and recommended closer cooperation between academic scientists and precollege educators. As a result, more industrial scientists have contributed to briefing teachers.

One project run by the Columbia University Teachers College involved more than 200 research scientists who are members of the New York Academy of Sciences. These experts offered minicourses, lectures, and workshops to educate teachers in topics selected jointly by the two groups. Many of the scientists later worked with the teachers in their classrooms in New York City school districts.

Teachers and laureates meet. High school science teachers in NSF's program for precollege teacher development talk with physicist and Nobel laureate Eugene Wigner. Under this project, Bard College of Annandale-on-Hudson, New York, organized lectures and seminars for science teachers to meet and share information with several eminent U.S. scientists.

In another project, Bard College of Annandale-on-Hudson, New York, organized a series of seminars and lectures in which Nobel laureates shared with teachers their contributions to modern science, their feelings about the future of science, and, most importantly, their ideas about how science is created. The laureates included Eugene Wigner, Arthur Kornberg, I. I. Rabi, Rosalyn Yalow, Willis Lamb, and George Wald. The teacher-participants were inspired and revitalized by this personal contact. They also learned directly about current advances in their fields and the beneficial applications of those advances. Private funds have been secured to edit and publish the 1980-81 lectures, which will also be broadcast on National Public Radio.

A recent survey conducted by the American Association for Higher Education indicated that very few colleges offer meaningful career-development programs for their faculty members. The Foundation has supported faculty development using different time periods of instruction for the various sciences and for engineering.

One such program will benefit some 1,400 college science instructors at 12 centers located throughout the country. For another hundred or so faculty members, NSF's industrial research participation program will mean research at 23 industrial, governmental, and nonprofit laboratories. Finally, NSF science-faculty fellowships will make it possible for nearly 100 teachers to pursue individualized programs of study and/or research for periods of 3 to 12 months.

Industrial options are part of all these teacher improvement programs. For example, Harold Wittcoff of the University of Minnesota taught a short course for faculty on industrial organic and pharmaceutical chemistry. Most of this material has not yet found its way into college textbooks.

Researchers aided by NSF's industrial research participation program had a rare opportunity to gain firsthand experience in highly technological research. For example, in one project participants worked with fiber optic materials at the Gould Laboratory in Rolling Meadows, Illinois.

About 30 percent of the science-faculty fellows chose a nonacademic host institution. Among them was Christopher G. Goff of Haverford College in Pennsylvania. He is at Collaborative Genetics in Waltham, Massachusetts, developing laboratory methods for a genetic study of some industrially important yeasts.

Experience shows that the students of faculty who have such industrial experience benefit through better career counseling; more up-to-date and relevant instructional materials introduced as entire new courses, new units in existing courses, or course enrichment; and a more meaningful and directed research experience. In many cases the host facility enhances this research experience by furnishing the needed supplies, sample materials, equipment, and expert advice and consultation.

Research Participation and Science Careers for Underrepresented Groups

NSF's research participation program works to attract students, especially minorities, to careers in science. Research apprenticeships for minority high school students help motivate these young people to pursue careers in science and engineering. Project directors reported very favorably on the performance of 226 student research associates in the cycle ending in May 1981. The 31 additional projects started in June 1981 meant opportunities for 420 more students.

Many projects also provided classes in technical writing and library research for students who needed those skills. About a third of the apprentices have written or helped write papers for scientific or educational journals.

This experience has motivated many minority students to plan their high school courses toward continuing their studies of science or engineering in college. Alabama A&M University offered three of the apprentices university scholarships as a result of their excellent work. Another student will attend the United States Coast Guard Academy.

Opportunities for women in science were offered through career workshops and facilitation projects. These activities helped women consider or reconsider careers in science. The workshops gave informal guidance on career options in science, mathematics, and engineering. Participants were undergraduate and graduate students, unemployed and underemployed degree holders seeking to reenter technical careers, and a limited number of high school seniors. The Foundation supported a total of 135 workshops in 37 states from 1976 through 1981; the sessions offered candid infor-

Science students train. These young people had the opportunity to work in the computer laboratory (top) and the biology laboratory (bottom) at York College, part of the City University of New York. They are among more than 4,000 talented junior and senior high school students who participated in NSF's student science training program in the summer of 1981.

mation and practical advice on career options in science and engineering and in sectors of the economy where prospects for employment are good. An estimated 3,600 women participated in 20 workshops in 1981.

As in previous years, the Foundation expects each institution to begin an activity that will continue after NSF support ceases. For example, Pacific Lutheran University will offer individual counseling on career objectives; academic courses to help students reach career goals; an information center on careers, jobs, and training programs; and use of an existing cooperative-education center to increase job opportunities.

Science-career facilitation projects retrained unemployed or underemployed women with at least a bachelor's degree in science, mathematics, or engineering. The Foundation supported 53 awards from 1976 through 1981. The 14 awards made in 1981 were primarily in fields where there are national needs for technical personnel and thus good opportunities for hiring and advancement. These fields include engineering, computer science, and chemistry.

As an example, the industrial and management systems engineering department of Arizona State University in Tempe offered 30 women the chance to earn master's degrees in information systems. Job opportunities are expected to be excellent in metropolitan Phoenix, which has more than 45 electronic equipment and aircraft and parts manufacturers.

The Foundation's student-oriented programs also enable high school and college students to work with university faculty or industrial scientists. These programs enhance the scientific strength of the nation by exposing the most talented science students to scientific pursuits and research. This allows them to assess career choices at an earlier stage.

In the student science training program, some 4,200 top secondary school students participated in research during the summer of 1981. This research and study was done under the direction of senior scientists or engineers. About 900 junior high students were among those involved.

These projects included talented handicapped students, with recruitment help given by the American Association for the Advancement of Science (AAAS). Project directors at institutions with appropriate facilities contacted the AAAS and were given test results for eligible handicapped students. Staff members from AAAS visited all 15 projects with handicapped participants and reported very favorable results. The AAAS is supporting a slide/tape presentation with a special focus on the participation of handicapped students in 1981 projects.

Undergraduate research. A Jackson State University student conducts a chemistry experiment during a summer undergraduate research participation program. The project allowed science and engineering majors to get firsthand experience in research outside the normal classroom and laboratory situations.

In the undergraduate research participation program, about 1,400 college or university students worked full-time for 10 weeks during the summer of 1981 with university science faculty or industrial scientists. In seven projects the colleges or universities directed the work at an industrial site. Twenty-seven of the projects were launched by students; there teams of two or three students collaborated directly with a senior scientist in designing the research activity.

Graduate Fellowships and High Technology

Since 1952, the Foundation has annually awarded graduate fellowships to some of the country's most promising and talented students. This support enables these students to pursue postbaccalaureate studies in science or engineering at institutions of their choice. In recent years, efforts have been made to increase participation in advanced levels of science by minority groups underrepresented in science and engineering. These efforts began in 1974 with a graduate traineeship program designed to support students enrolled in graduate programs at predominantly minority institutions. This program was expanded in 1978 by the offer of portable fellowships to especially promising individual minority students identified in a national competition.

These programs have sought to support the best students among the applicants in mathematics, engineering, and all of the physical, life, and social sciences. Many of these students are in the forefront of research in high-technology fields. Four examples of work by Fellows supported in FY 1981 are as follows:

- In the areas of genetics, Thomas G. Chappell, in biochemistry at Stanford University, is working to clone membrane protein genes that may be transferable among the cells of higher life forms.
- Robert J. Hamers, in physical chemistry at Cornell University, has designed and constructed a laser system that selectively excites molecules in a molecular beam.
- Eric R. Salberta, in the plasma physics laboratory at Princeton University, is doing theoretical and applied research on very high energy plasmas of nuclear-fusion reactions.
- Also in physics at Princeton University, Jonathan A. Bagger has coauthored a set of lectures on supersymmetry and supergravity.

Thus, through three NSF programs—faculty improvement, research participation, and graduate fellowships—students benefit at all stages of their science careers. They are also in a better position to contribute to the nation's productivity.

Science Education Resources Improvement

The purpose of these programs is to advance the nation's science capability by improving the quality of educational programs in science and engineering at academic institutions. In 1981 NSF supported more than 400 such projects through three major areas of program activity.

Improvement in the quality and effectiveness of undergraduate science education came from the CAUSE program—comprehensive assistance to undergraduate science education. Its two major objectives are to strengthen science instruction at the undergraduate level and to enhance an institution's capability for self-assessment and continuous updating of science programs. In 1981, 41 CAUSE grants went to institutions in 34 states, the Virgin Islands, and Puerto Rico. The awards, averaging $205,800, benefited 10 two-year colleges, 19 four-year institutions, 11 Ph.D-granting institutions, and 1 consortium of 15 two- and four-year schools.

Undergraduate instructional improvement aids college-level science teachers in two ways. Awards under the local course improvement (LOCI) program have these goals: to speed incorporation of the results of recent scientific research into the undergraduate curriculum, and to give science faculty an opportunity to develop innovative teaching methods. The instructional scientific equipment program strengthens undergraduate classroom, laboratory, and field experiences through grants for the purchase of up-to-date laboratory instruments and current educational technology.

In 1981 LOCI made 114 awards to 101 colleges and universities in 38 states in amounts ranging from $3,998 to $30,000. Under the equipment program, 245 awards of up to $20,000 went to 200 colleges and universities in 45 states and the District of Columbia.

In all of these activities a substantial institutional contribution is required. Thus the $14.1 million awarded to projects in 1981 by CAUSE, LOCI, and the equipment program represents an estimated additional investment of more than $8 million by grantee institutions and private sources.

The resource centers for science and engineering program gives support to set up academic centers for graduate, undergraduate, precollege, and community activities. The purpose here is to encourage talented persons from underrepresented ethnic minority groups and from low-income families to pursue careers in the sciences. This year the fourth in a series of awards begun in 1978 was made to the City College of New York to establish such a center.

Field Experience in Undergraduate Mathematics

The mismatch between traditional academic training in mathematics and the current and predicted job market for mathematicians is receiving increased attention. Evidence of this mismatch is widespread. Steadily declining enrollments in graduate mathematics are accompanied by a general shift of student interest to applied mathematics. There is a new focus on the role of

Table 8
Science Education Resources Improvement
Fiscal Year 1979, 1980, 1981

(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Comprehensive Assistance to Undergraduate Science Education	72	$13.52	66	$13.28	41	$ 8.89
Undergraduate Instructional Improvement	435	6.40	343	5.68	349	6.17
Resource Centers for Science and Engineering	1	2.74	1	2.75	1	2.77
Information Dissemination	36	1.03	41	1.27	*	*
Total	**544**	**$23.69**	**451**	**$22.98**	**391**	**$17.83**

*Included under Science Education Communication in FY 1981

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Improving science education. This college student is working on a physiology experiment made possible by a grant under NSF's CAUSE program (comprehensive assistance to undergraduate science education). CAUSE projects improve training in science and engineering at academic institutions. (Photo by Ian Mizzi) the industrial mathematician, and some new M.S. and Ph.D. programs emphasize training for nonacademic employment. At the undergraduate level, new courses will simulate industrial application of mathematics.

A recent NSF grant to Oberlin College lets undergraduate students gain experience in applying mathematics to actual problems, in addition to their usual classroom instruction. The problems come from local business, industry, or government "clients"; student research teams try to solve them. The project director developed the idea after learning of a similar NSF-supported project in California.

One of the first problems the Oberlin students tackled came from a multinational company that manufactures industrial products for painting, sealing, and packaging. A corporate objective is to have a large enough stock of parts on hand to satisfy 95 percent of all orders when they are received. Thus $15 million worth of inventory covering 20,000 individual items is normally held at the main plant.

It is to the company's financial advantage to have the lowest possible number of parts on hand and still be able to meet this 95 percent commitment. However, since there is great uncertainty as to what parts will be ordered, when, and how many, there is a reserve supply of many items. The purpose of this project was to study a selected number of items for fluctuations in demand and the consequent variation in inventory level maintained, and then to recommend an appropriate policy on the stock inventory for those parts.

Four seniors and one junior made up the team that worked on this problem. They selected seven typical parts and traced their inventory histories for more than a year. They developed a simulation model using such factors as average weekly demand, the variability of that demand, the time required to fill a replenishment order, and the critical quantity necessary to trigger a replenishment order. After refinement, this model allowed the team to predict how many of each item had to be kept on hand to meet the 95 percent commitment. The results show that for all but one of the parts studied, the inventory normally on hand was considerably larger than required. Assuming inventories for these seven parts are representative, this model, when applied to all the parts normally carried in stock, could mean large savings through reduced inventory.

Microcomputers in the Chemistry Laboratory

Over the past decade, there has been a revolution in digital electronics and computer technology. Advances in large-scale integrated (LSI) circuits have produced low-cost individual chips that can carry out operations formerly needing many hundreds, even thousands, of discrete electronic components.

The most remarkable of the new LSI devices is the single-chip microprocessor, an integrated circuit with at least 75 percent of the power of a small computer. When coupled with memory elements, control circuitry, and data input and output lines, this device results in a fully operational computer system on a microcomputer scale. Thus it is now possible to incorporate digital computing devices into chemical laboratory instrumentation and to realize great improvements in accuracy, sensitivity, and reliability at a fraction of former costs in money, time, and hardware. (Until recently, the introduction of computers into the chemistry laboratory meant an investment of around $50,000 for the computer alone.)

Indications are that the pace of computer usage in the chemistry laboratory will speed up in the coming years, with microprocessors and microcomputers playing a major role. It is necessary, then, to make sure undergraduate chemistry students have "hands-on" experience with state-of-the-art computer techniques for data handling, data reduction, and experiment control. Such experience is important to these students in their later work in graduate school, research, or industry.

In the past three years, the number of awards in this area has gone up. A grant to the chemistry department at the University of North Carolina at Chapel Hill illustrates one of several possible approaches.

At Chapel Hill, data-acquisition techniques will be applied to the software-level laboratory. Gas chromatographs and ultraviolet spectrophotometers now in use will be linked to 10 microcomputer systems. Each microcomputer printer system will run eight chromatograph and spectrophotometer experiments simultaneously. In addition, data-file modules of infrared, mass spectroscopy, and nuclear magnetic resonance will be created and stored on a disk for teaching interpretation of common spectra. Some 250 chemistry majors and several hundred other science majors a year will gain a working knowledge of modern data-acquisition techniques and computer control.

New York Resource Center for Science and Engineering

This year the City College of New York (CCNY) received a grant to develop a Resource Center for Science and Engineering. This is the fourth in a series of major awards started in 1978 to promote increased participation in science and engineering by minorities and persons from low-income families.

About 60 percent of the total undergraduate student body at City College major in a biological, engineering, mathematical, physical, or social science. Some 3,500 of these students are minority-group members. This large enrollment may be attributed partly to the fact that the only engineering school of the entire City University of New York (which has 18 separate institutions) is housed at CCNY. But the figure also reflects the college's long and continuing tradition of strength in both the natural and social sciences and its strong efforts to attract students in these disciplines to the campus.

The geographical area from which City College draws its enrollment is populated by the highest concentration of minority groups and low-income families in the nation. Over a four-year period, the resource center plans a variety of on- and off-campus programs and services to create new opportunities for study, research, and career counseling in science. The activities will be aimed at students from elementary through graduate school, parents, school and college teachers and administrators, and the general minority and low-income community.

The center's precollege and undergraduate education divisions plan to work with area elementary and secondary schools, as well as two- and four-year colleges, that have large minority and low-income enrollments. The coalitions will provide enrichment programs to improve the science skills of these students.

In addition, these two divisions expect to offer workshops in science course and career guidance; they will also run programs to provide a smooth transition into science and engineering study for both high-school and community-college students. Other efforts call for coordinating the exchange of education and career information between participant institutions and encouraging the effective use of public and industry-sponsored science exhibits and resources.

Through its research and graduate education division, the center will provide student assistantships and will conduct a transition program for entering and prospective graduate students. New minority faculty members in science and engineering will be hired and given considerable research support. The center also plans a program to host minority faculty on sabbatical leave from area colleges and schools to enhance their professional development.

Parents and other groups in the minority and low-income communities will be reached through the community activities program. Its work will include displays and other aid for local organizations and a science resource service to help local industry and others seeking technological advice.

The center's importance can be summed up in a single statistic: only 4 percent of the bachelor's degrees in engineering awarded in the United States last year went to Black and Hispanic Americans. To counter this, the CCNY center will try to reach minority students early, making sure they get the fundamental preparation that can lead to later opportunities for doctorates or other rewarding careers in engineering and science.

Science Education Development and Research

In any enterprise based on technology, research and development are the cornerstones of long-range strength and growth. In science education they assure that instruction in the sciences can be up-to-date, reflecting the best current work in the various fields.

NSF's programs in science education development and research support these activities:

- Continuing development and publication of high-quality instructional materials based on the latest research and technological findings.
- Research to promote the acquisition, use, structuring, and transfer of knowledge and skills in science, mathematics, and engineering.

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 research. Research in science education gives us new ways to view the processes of learning—how learners develop scientific skills and knowledge. These programs at NSF are guided by three overall objectives:

- To strengthen the scientific work force, making sure it is continually replenished by well-prepared graduates and that continuing education opportunities are adequate to keep them up-to-date. Special attention is given to methods for increasing access by women and minorities to scientific careers.
- To increase the flow of new science and technology into courses and other instructional materials. Much depends on the diversity of course materials available, and whether what is being taught represents the latest and most significant knowledge. Such knowledge is important to current concerns in productivity and to the individual's ability to compete effectively in the scientific and technical job market.
- To increase the science competency of all citizens—specifically their knowledge of scientific concepts, of the methods and limitations of science, and of relationships among science, technology, and society. This goal is addressed by projects both inside the school system and in informal, out-of-school settings.

These objectives are approached in two ways. Development-centered projects enable teams of scientists and educators to produce new science courses, new curricula, and new approaches to science teaching. Research-centered projects include basic and applied research and the synthesis of existing research to create and organize fundamental knowledge of science education.

The Foundation's R&D programs in science education specialize in support for long-range efforts to anticipate the problems and opportunities of the future. Many projects are aimed at conditions 5 to 15 years away; their goal is to make sure that major problems are both identified and examined by the most highly qualified and talented people available in the science and engineering communities.

These areas received particular emphasis in 1981:

- *Education for productivity*—National productivity and economic progress increasingly depend on the ability of a society to capitalize on new technological opportunities. In recognition of this need, especially in engineering and applied sciences, NSF supports research and development aimed at the rapid infusion of the latest and most promising science and technology into higher-education courses.
- *Technology in science education*—The power and increasing availability of computing equipment, especially microcomputers, have vital implications for the nature and content of science teaching at the undergraduate and graduate levels. NSF aids both

Table 9
Science Education Development and Research
Fiscal Year 1979, 1980, and 1981

(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Development in Science Education	53	$ 8.18	52	$ 8.11	58	$ 6.16
Research in Science Education	40	3.83	46	5.68	39	4.71
Total	**93**	**$12.01**	**98**	**$13.79**	**97**	**$10.87**

SOURCE: Fiscal Year 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Problem-solving skills. Physical representations help students organize data. These children are part of an NSF-supported project at the University of California, Berkeley, called SPACES—solving problems of access to careers in engineering and science. SPACES helps young students develop and build mathematical problem-solving skills; its aim is to motivate them to pursue later study and work requiring those skills. The project puts a special emphasis on females, who are underrepresented at the higher levels of math and science study. (Photo by Eileen Christelow)

research and development to incorporate computing into classroom and laboratory practice, and into instructional materials.

- *Problem solving*—The ability to perceive, define, and solve problems is essential to science and engineering. It is also an important factor in the skilled technical work upon which productivity depends. There is increasing evidence, however, that most students in science, mathematics, and engineering are relatively unskilled at setting up and solving problems. The Foundation backs research on problem solving in the various fields of science and engineering, and the development of materials to strengthen the teaching of these skills in academic and professional programs.

Education 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 the curricula of schools and universities. For the past three years, NSF has been supporting projects to explain this lag and, more importantly, to reduce it.

During FY 1981, NSF emphasized the development of networks and consortia of local institutions working together for self-help. Their aims are to promote technology transfer and resource sharing and to solicit enough outside contributions to become self-sustaining. Some examples are as follows:

- As part of an international movement organized by Rustum Roy of Pennsylvania State University, a U.S. national committee will analyze and recommend reconstruction of the materials science and engineering curricula. It will also develop a self-sustaining consortium of colleges and universities to exchange, review, and revise instructional materials that introduce the latest technical and theoretical advances.
- Under the leadership of Alfred Bork of the University of California, Irvine, six universities will organize a national consortium. These schools are now heavily involved in inservice workshops to train teachers in how to use

computers in precollege science courses. They will combine materials, rewrite those now available, and publish programs and instructional materials that foster technological competence.

- The college Consortium for CAD and CAM (Computer-Aided Design and Computer-Aided Manufacturing), led by John E. Gibson of the University of Virginia, began with 12 engineering schools as members. It will soon double in size, including industrial firms and more engineering colleges. The primary work of the group is to exchange curriculum materials and instructional software, and to encourage faculty rewards for contributions to educational revitalization. The consortium members will rewrite the bulk of the undergraduate engineering curriculum to integrate the use of computer aids and to emphasize design.

Continuing education is a distinct and crucial link between technical education and productivity. In recent years, NSF has funded more than 25 projects on the assessment of needs and courses in continuing education for engineers. An award to the Association for Media-Based Continuing Education for Engineers has set up a nationwide network to develop, exchange, distribute, and deliver media-based continuing education programs and courses. This network responds to the needs of a wide range of engineers in nonacademic jobs. More than 90 percent of all media-based efforts in engineering are authored through this association, and more than 30,000 engineers are enrolled in some 1,200 of its courses.

An award to the Institute of Electrical and Electronic Engineers has produced a highly successful and much-in-demand system for validating education achievement through continuing education credits. A survey done by Virginia's George Mason University has come up with new tools to (1) identify the most urgent educational needs of engineers in a given geographic area, and (2) determine the magnitude and effectiveness of educational efforts to meet those needs.

A continuing education project at the Virginia Commonwealth University is designing graphing lessons to be used interactively with a computer graphics terminal on an individual and personalized basis. This will complement the teaching of adult courses in elementary algebra, intermediate algebra, and trigonometry.

Several continuing education projects supported by NSF have the added thrust of improving the access of women to careers in science. One such project (jointly funded with the Department of Education's Fund for the Improvement of Postsecondary Education Program) is at the Polytechnic Institute of Brooklyn. It builds on the findings of several NSF-supported projects that explored the reentry of postbaccalaureate women into science and engineering careers. The project shows educators how to carry out successful strategies to retrain women whose undergraduate studies were in science or science-related fields, but who have been either unemployed or underemployed for some time.

Another project, at the University of California, Santa Barbara, is developing a computer-based mathematics program for women who wish to upgrade their skills, continue their education, or reenter the job market. Based on a concentrated immersion in mathematics through lectures, instructional modules and videotapes, tutorial and microcomputer laboratory sessions, and individual attention, the project will involve control and treatment groups. A followup study of the participants will measure effects on their employment potential.

Technology in Science Education

The use of science and engineering technology in both industrial and academic research and development is now routine. Knowing how to use technology, especially the computer, has become a prime requirement in science and engineering education and a major focus for the Foundation.

In the development area, more than 20 projects involving new uses of computing technology began in FY 1981. Most of these focus on the low-cost, versatile microcomputers and their potential for greatly improving junior and senior high school mathematics learning. For six of these projects, the National Institute of Education transferred funds to NSF for partial support of the work.

Some NSF-supported projects on computing in precollege mathematics are as follows:

- Carl Davis at the North Carolina School of Science and Mathematics is creating

Technology in science education. High school science and mathematics teachers attend a summer workshop at the North Carolina School of Science and Mathematics, where they learn ways to use microcomputers in their courses. The workshop was supported by NSF's program for science education research and development.

courseware that shows the use of mathematics in chemistry, physics, and biology laboratories. Students with identified math/science aptitude will use microcomputers to apply in the science laboratory principles learned in the mathematics classroom.

- Sharon Dugdale of the University of Illinois at Urbana-Champaign is developing prototype microcomputer software to teach functions and graphs at the high school level. The materials provide motivating activities such as mathematical games; these also have the merit of being direct expressions of the underlying mathematics principles addressed in the lesson.
- Eugene Klotz of Pennsylvania's Swarthmore College is designing microcomputer color-graphics units for high school trigonometry courses. Students can explore these units either on their own or under the direction of a teacher. The materials will be highly visual in character and will be written to let students choose their own paths through the lessons, rather than following a predefined track.

Problem Solving

The National Science Foundation has continued its investment in projects designed to contribute important knowledge about learning, participating in, and applying science and mathematics. NSF has kept the general goal of increasing access to science by minorities, women, and the physically handicapped, along with the goal to strengthen the relationship between research and development within and across projects. The Foundation continues to emphasize the importance of understanding (1) the relationship between thinking and the structure of knowledge in different fields of science, and (2) the various roles computers can play.

These goals and approaches coalesce in problem solving, which has assumed an increasingly prominent role in both instruction and research in science and mathematics. Although the importance of problem-solving skills is clearly recognized, investigators find that many students in science, mathematics, and engineering classes lack these needed skills. Several NSF-funded projects have given evidence of this lack. This finding extends to many students who receive outstanding grades in their science and math courses, and even to many teachers at the precollege level.

One major reason for this poor performance is that many students lack an adequate understanding of certain substantive science or mathematics concepts. In addition, many students are hampered by a failure to monitor their own problem-solving performance. One result of these failures is that students assume they cannot "do" mathematics or chemistry or physics. They then lose the motivation to pursue studies or careers requiring these concepts or skills.

Several recent studies supported by NSF have documented specific obstacles and offered some promising instruction strategies to overcome them. Furthermore, it is encouraging to note that the successful strategies seem to share some interesting commonalities, such as engaging the students in repeated discussions and experimentation on the concepts and phenomena involved. It is also reassuring to note that researchers in other countries are reporting favorable outcomes from this kind of approach. Moreover, the findings are extending from physics and mathematics into other sciences, such as biology and chemistry. Further tests on generalizing these findings across disciplines, student age levels and backgrounds, and to the "world of work" would be valuable.

The computer seems likely to hold special promise for the learning of science and engineering and for developing skills to solve problems in those domains. Low-cost, high-performance microcomputers with graphical displays make possible the modeling of science and engineering concepts and the display of relationships in visual form. Now appearing is powerful software that will enable such systems to offer computer-assisted instruction. It will also mean that students can program mathematical models of their understanding of conceptual relationships in science and mathematics.

These forms of presentation are more appealing than words and formulas to many students; they seem to provide an important intuitive "bridge" to understanding. The advantage may be particularly important to those who would otherwise drop out of science and mathematics.

Several projects are using microcomputer-based graphics in the study of learning in science and mathematics. For example,

Early learning of geometry and logic. Young children learn mathematics in a playful, interactive manner using low-cost microcomputers with color graphics, natural-sounding speech, music, and a variety of input devices. Computer programs for children aged seven and eight are being developed by Advanced Learning Technology Corporation. In addition, mathematicians at Northwestern University are using microcomputers to study the way children learn about counting and early number concepts.

mathematicians at Northwestern University are studying how children learn about counting and early number concepts. They present various mathematical pictures to very young children and then collect and analyze the resulting data, all by microcomputer.

The computer is helping in other ways as well, primarily as instrumentation in research on the learning of science and mathematics. Understanding of the knowledge and processes used in solving problems has been deepened by the act of writing programs that can solve classes of problems. Furthermore, the computer is a highly stable instrument for presenting science concepts (or other research stimuli) and for recording and analyzing student responses.

Science Education Communication

Communication activities focus on (1) the public's need to know about and understand the activities, methods, and implications of science and technology, and (2) a need for professional science educators to be aware of new developments and methodology in their constantly changing fields. In both these cases the audiences are diffuse and their varying information needs are poorly served. The following programs are an attempt to meet those needs.

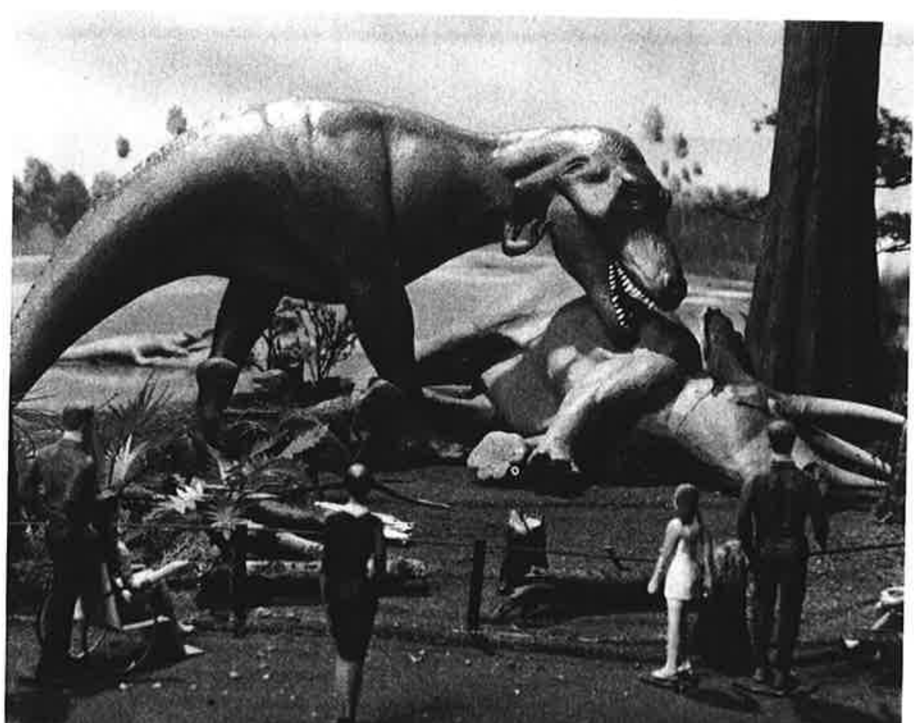
Public Understanding of Science

Despite an increasing interest in science and technology, most nonscientists remain poorly informed. Students not intent on professional careers in technical fields seldom pursue science beyond 10th-grade biology, and only about 20 percent of the public considers itself reasonably well informed. This NSF program has supported and encouraged a variety of media to help the public learn about science issues in an informal and recreational milieu. The program focuses largely on mass communication, through a combination of broadcasting, science museums, and journalism. These media reach large and diverse audiences, have significant impact, and are particularly cost effective. Most projects reach audiences of 5 to 10 million people and are chosen to reflect a wide range of interests, ages, and subjects.

For example, the public television series "NOVA" has been reaching an audience approaching 10 million; the daily children's science series "3-2-1 Contact" is viewed by an audience of 23 million, including 6,000 homes without children. During the past year, the Girl Scouts of America set up a science badge program to tap the interest and excitement generated by "3-2-1." Similarly, science museums in several cities began special weekend activities to provide further hands-on experience paralleling the program's content.

This broad impact of public television is complemented by several new radio series. They attract a wide audience and offer daily discussions of current science news and issues. In the past year National Public Radio (NPR) set up a science news staff and production center that provides a continued flow of science material to "Morning Edition" and "All Things Considered." These morning and evening NPR news programs reach an audience of more than 4 million. In addition, the center provides periodic programs on special topics and a weekly "feed" of science materials for use by local public radio stations. The project also supports regional science-reporting centers in Boston and San Francisco.

Along with public broadcasting, a weekly science news report producted by Don Herbert (Mr. Wizard) is now incorporated in the local news programs of 140 commercial television stations. Success in this difficult and extremely competitive arena results from several years of experimentation with the problems and potential of distribution by commercial syndication channels. The increasingly popular series reaches an estimated 8 million persons weekly; it is jointly supported by grants from NSF and General Motors Research Laboratories. Many broadcast projects operate on such cooperative funding, and during the past year several projects involved supplementary funding by the public broadcasting entities of other countries.



How it used to be. A key public understanding of science project will be this exhibit on the earth's early history, being developed at the Milwaukee Public Museum. This exhibit will be duplicated and sent to other museums around the country.

The Foundation has strongly encouraged cooperative activities by science museums. It gave support to create the first association of these museums and continues to back the association's traveling exhibits. Successful museum exhibits often involve long and costly design and development activities by small groups with near-unique skills and expertise. To make the best and least expensive use of these resources, NSF has encouraged the production of duplicate exhibits. The talent and skills of major institutions can then be made available to a much larger audience.

During the past year, the National Museum of Natural History in Washington, D.C., unveiled a new exhibit featuring a live coral-reef ecology with more than 200 species of fish, plants, and crustacea. The display is unique, and a working marine laboratory is an important part of it. The museum plans to build several replicas of the exhibit for other large museums throughout the country, simultaneously reaching a much larger audience and establishing new marine biology research centers. Both exhibit and laboratory are very popular and are expected to reach an audience of more than 10 million a year.

Similarly, the Oregon Museum of Science and Industry has developed an elaborate computer science exhibit over a period of several years. The displays include not only demonstrations of computer logic but also hands-on examples of how computers are used in science careers. Like the coral reef, the computer exhibit will be duplicated and installed in medium-size museums throughout the country.

Table 10
Science Education Communication
Fiscal Year 1981

(Dollars in Millions)

	Fiscal Year 1981	
	Number of Awards*	Amount
Public Understanding of Science	20	$4.30
Information Dissemination	36	1.22
Ethics and Values in Science and Technology and Science for Citizens	64	3.07
Total	**120**	**$8.59**

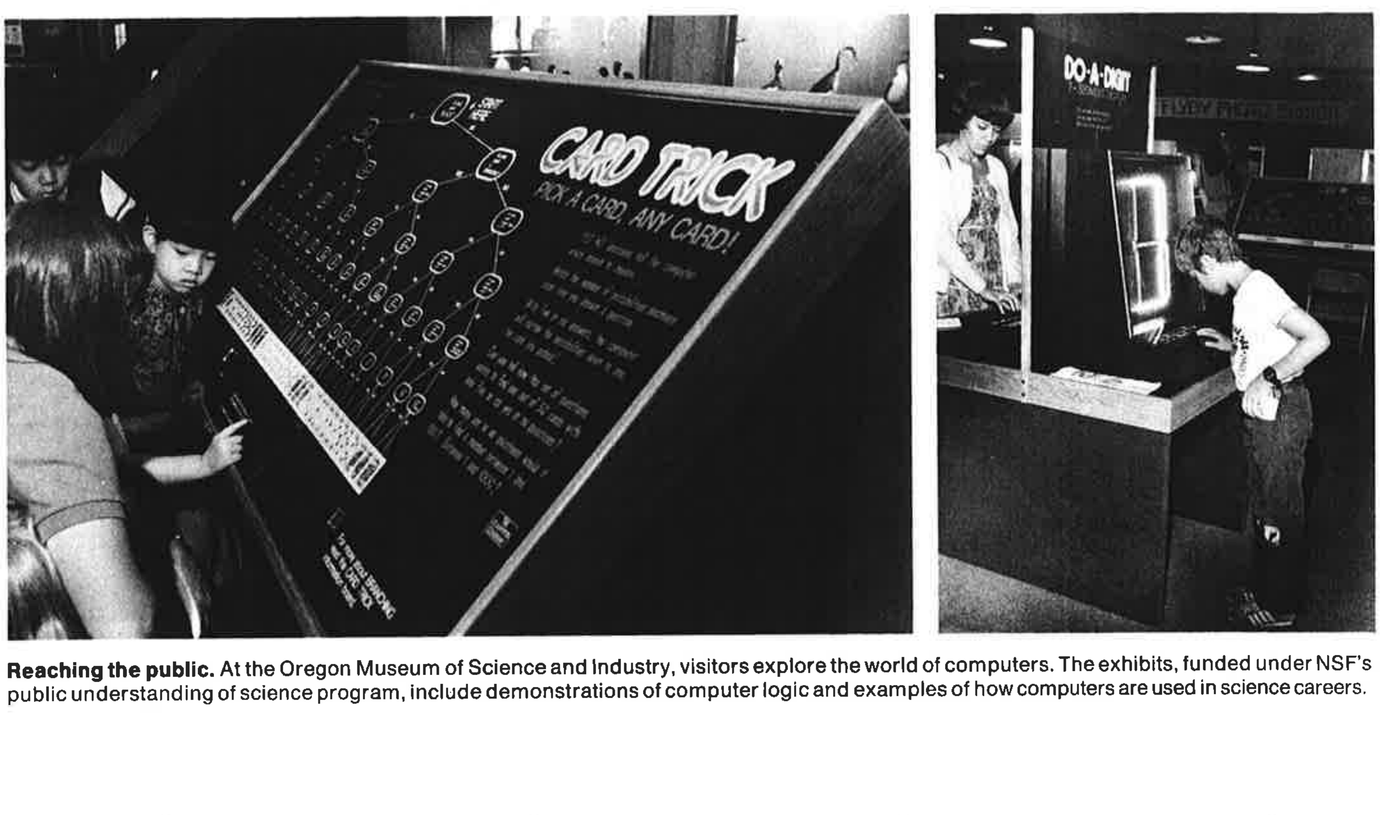
*Includes joint awards made with transfer of funds from other agencies: Department of Education $1 million, National Institute of Mental Health $50,000

SOURCE: Fiscal Year 1983 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

Bridging the Gap Between Educational Developers and Users

Information dissemination for science education is a program for administrators, specialists, school board members, and other decision makers in state and local school systems. It helps them examine and evaluate instructional materials and practices in science, mathematics, and social science before selection and use. The 30 awards made in 1981 to conduct conferences and workshops will make these decision makers more familiar with the many instructional materials, practices, and technologies available for use in elementary and secondary schools.

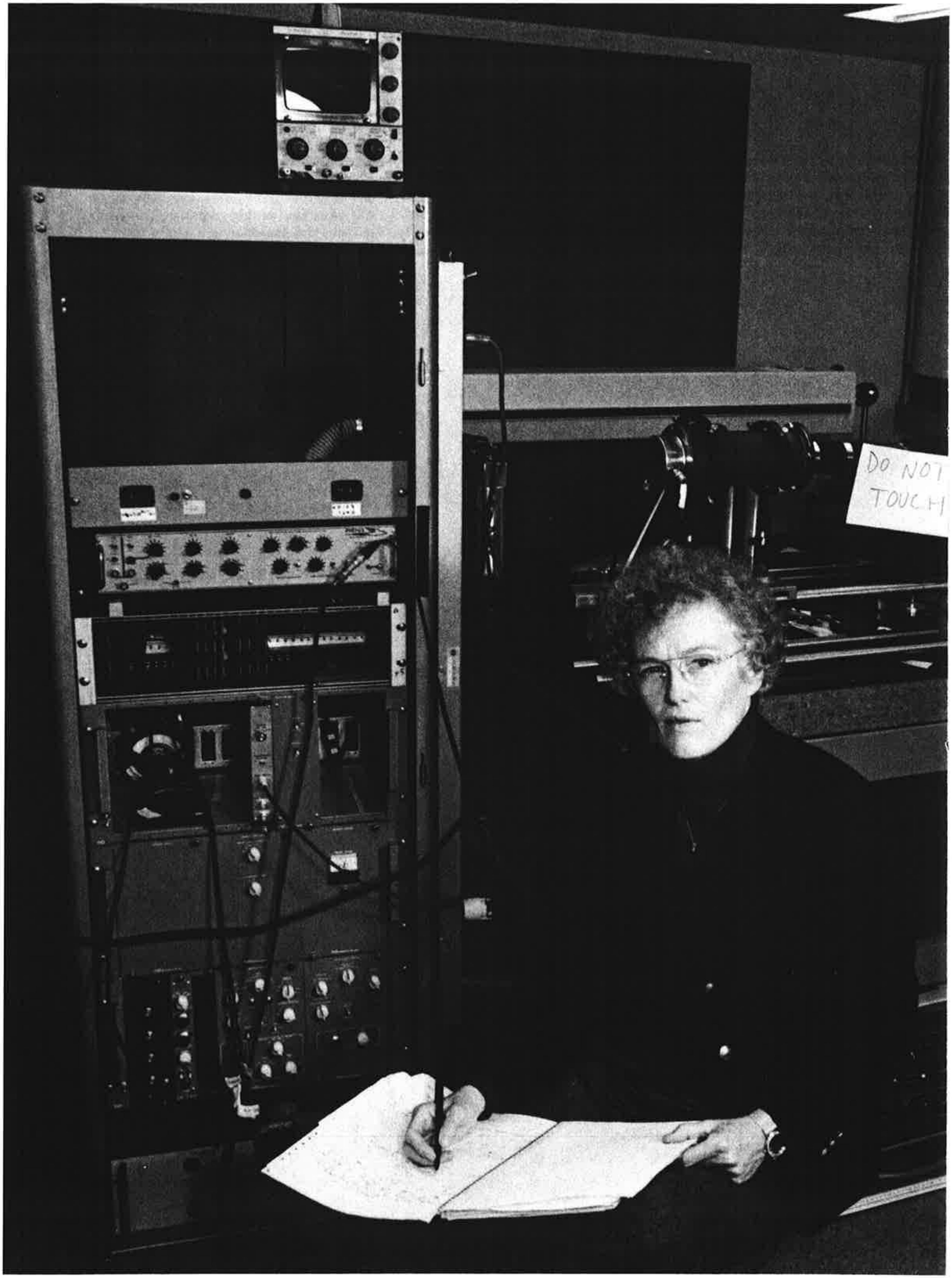
Projects that expose participants to new curricular materials are underway at Emory University in Georgia and the University of Hawaii. The University of California,



Reaching the public. At the Oregon Museum of Science and Industry, visitors explore the world of computers. The exhibits, funded under NSF's public understanding of science program, include demonstrations of computer logic and examples of how computers are used in science careers.

Berkeley, is arranging conferences on calculator-assisted mathematics materials, teaching ideas, and strategies that involve calculator hardware and commercially available instructional materials.

In some projects, information on current research findings in precollege science and mathematics education is presented along with potential classroom applications. The University of Iowa is working with state science curricula supervisors, university faculty, and local school personnel on regional conferences in Iowa and Missouri. These conferences will focus on new areas of intellectual development and their implications for helping secondary school students develop reasoning ability while learning science.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Cross-Directorate Programs

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A number of the Foundation's research activities have implications and importance that are agencywide; they are grouped together in the cross-directorate programs. Along with advancing particular areas of science, these programs support the additional goal of strengthening and broadening the science and engineering base of the nation. They are designed to do the following:

- Establish specialized, sophisticated regional facilities to aid research requiring state-of-art instrumentation.
- Provide moderate-cost research instrumentation to institutions having limited doctoral programs (or none) in the sciences and engineering.
- Help minorities and women pursue individual research careers.
- Broaden the competition for federal research support through grants to institutions in certain states that historically have been less able to compete successfully.
- Gather and analyze information to help NSF identify and resolve key policy issues.

Research Facilities and Instrumentation

Two programs work to strengthen basic research capabilities in colleges and universities by making research instruments and facilities available. Each program stresses the importance of providing greater scientific opportunity through some form of equipment sharing.

Two and four-year college research instrumentation

This NSF program provides research instruments of moderate cost to colleges and universities that lack doctorate programs in sciences and engineering or have only small ones. In fiscal year 1981, some 140 grants went to about 110 different American colleges and universities. The largest number of awards were in chemistry and biology; also aided were investigations in astronomy, engineering, geology, physics, and psychology—in fact, more than a dozen areas. The maximum award was $35,000; the average was about $19,400.

Much of the equipment is shared by several investigators working on different projects. The awards enable faculty members with recent Ph.D. degrees to retain the research momentum acquired in their graduate training. This would often not be possible because of the common lack of modern instruments in nondoctorate institutions. In addition, projects often involve undergraduate assistants who learn how to use modern instruments while working on faculty research projects.

Some examples of instrumentation awards:

- Using a residual gas analyzer, vacuum pumps, and other equipment acquired through this program, A. C. Lawson and others at Pomona College in Claremont, California, are examining the superconducting properties of pseudobinary alloy systems. Studies of the properties of thorium compounds could yield results critical to understanding the periodic systems.
- Stephen K. Taylor of Olivet Nazarene College in Kankakee, Illinois, was investigating epoxides with a liquid chromatograph and accessories provided through this NSF program. He serendipitously discovered and developed two new procedures for polymer research, which he has published in chemical journals. These results were unplanned but could not have happened unless the investigators were prepared to recognize them and had equipment to make the necessary observations.
- Sister Mary L. Wright, of the College of Our Lady of the Elms in Chicopee, Massachusetts, is investigating the

Table 11
Cross-Directorate Programs
Fiscal Year 1979, 1980, and 1981

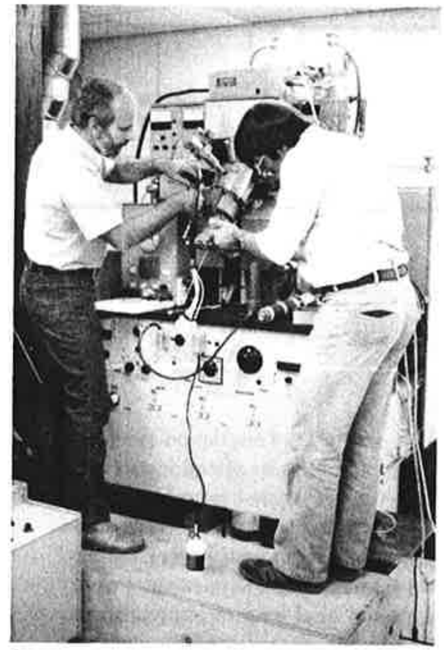
(Dollars in Millions)

	Fiscal Year 1979		Fiscal Year 1980		Fiscal Year 1981	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Industry-University Cooperative Research	57	$ 5.44	74	$ 5.05	*	*
Research Facilities and Instrumentation Programs	55	5.61	199	7.83	158	$6.15
Other Programs	71	5.81	61	6.13	149	10.46
Total	**183**	**$16.86**	**334**	**$19.01**	**307**	**$16.61**

* Included under Scientific, Technological, and International Affairs, Industrial Science and Technological Innovation in FY 1981

SOURCE: Fiscal Years 1981, 1982, and 1983 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables)

New instruments. Under its two- and four-year college research instrumentation program, NSF helped Wellesley College acquire new equipment for its departments of chemistry, physics, and biological sciences. Here a physics professor is shown with instrumentation for a light-scattering study. (Photo by Cynthia R. Benjamin)



Regional instrumentation facilities. Researchers install a part on the triple-sector mass spectrometer at the Midwest Center for Mass Spectrometry, Unviersity of Nebraska-Lincoln. This piece of equipment is an example of what NSF supports under its regional instrumentation facilities program. The facilities serve a wide range of research interests and offer access to sophisticated equipment for scientists at several institutions.

rhythms of cell proliferation in tadpole limb epidermis and the effects of the metamorphic hormones thyroxine and prolactin on these rhythms. Her work, assisted by undergraduate students, includes a study of how cell-proliferation rhythms respond to changes in the normal light/dark cycle.

An award from NSF has made it possible for this researcher to acquire a liquid scintillation counter, a research microscope with camera attachments, and a microcomputer system. These have increased the productivity of this small college's ambitious program to investigate circadian rhythms, the factors that regulate cell division, and hormonal interactions with biological rhythms.

Regional instrumentation facilities

These facilities cover a wide variety of research interests, including nuclear magnetic resonance spectrometry, mass spectrometry, lasers, carbon-14 dating, electron microscopy, and surface science. The facilities provide highly specialized research opportunities for a broad group of scientists. Disciplines served range from environmental science and chemistry through biochemistry and medicine to materials science. Access to the unique capabilities of each facility has benefited industrial, government, and academic researchers.

The diverse style of these regional centers includes the carbon-14 dating facility at the University of Arizona, where a single large instrument constitutes the facility. Then there is the laser lending library at the San Francisco Laser Center, hosted by the University of California and Stanford University. This center offers a unique opportunity by providing lasers for short-term use in individual researchers' laboratories.

Scientific advances made possible by regional facilities include these:

- Arizona State University has succeeded in obtaining diffraction patterns from areas as small as 10 to 12 angstroms; this opens up a new dimension in the study of microcrystals and structures of thin films.
- Workers at the Regional Laser Center at the University of Pennsylvania are studying the mechanisms of reactions at the sub-picosecond level. This allows the interpretation of many reactions involving transient species in such applications as catalysis, polymerization, and other gas-phase reactions.

Research Initiation and Improvement

These programs address the needs of both individuals and groups of researchers in states where developing research competitiveness is a high priority. Support also goes to new doctoral scientists and engineers, allowing them to gain more technical skills and new insights into current research problems.

Minority research initiation

This program gives research support to faculty members who are U.S. nationals and members of ethnic minority groups that are underrepresented in science and engineering. Research proposals may be submitted by eligible minority faculty members of any college or university who have not received any federal research support as faculty members.

The program represents an integral part of the Foundation's continuing effort to provide greater access to scientific and engineering research by minorities. It addresses the need among minority researchers to begin federally supported research projects as new principal investigators in all scientific and engineering disciplines.

In fiscal year 1981 NSF made 19 awards under this program, for a total of $1.4 million and an average award size of $37,000 per year. Seven awards were made to predominantly minority institutions: Atlanta University, Howard University (3 awards), Jackson State University, Meharry Medical College, and the University of Puerto Rico. The other awards went to Arizona State University and Michigan State University; to the Universities of Alabama, Colorado (2 grants), Illinois, Massachusetts, Southwestern Louisiana, Texas, Washington, and Wyoming; and to Virginia Polytechnic Institute.

On a regional basis, grants were awarded to 10 colleges and universities in the South and Southwest, 8 in the West and Midwest, and 1 in the East.

One project will examine whether changes in DNA superstructures, mediated by reversible and irreversible interactions among chromosomal proteins, are involved in the control of cell proliferation and perhaps cellular aging. Another, a mathematics project, will focus on the numerical study of dissipative dynamical systems and their attractor sets.

Using special analytical techniques, researchers will examine the effects of several types of insults applied at various times within the period of brain growth. The purpose of this project is to test the hypothesis that during the phase of rapid brain growth, which occurs late in the development of the central nervous system, the brain is more vulnerable to traumas than at any other time and the effects of such traumas are permanent.

Other projects will be in such broad research areas as brood parasitism, protocol investigation for local computer networks, cellular differentiation using unique experimental models, control mechanisms for mitochondrial proteins, and economic and ethnic solidarity theories.

Minority research initiation. These electrical engineering researchers at Howard University are working under one of three awards made to that institution in 1981 through the minority research initiation program.

Experimental program to stimulate competitive research

This program was created to improve the quality of science and engineering in selected states and to increase the ability of scientists and engineers to compete successfully for federal research funds through the accepted peer-review process. The program recognizes both the local and national importance of a strong science base and the benefits of a diverse and widespread pool of performers.

In fiscal year 1981, NSF awarded $3.4 million to continue programs begun the year before in five states: Arkansas, Maine, Montana, South Carolina, and West Virginia. Each award supports research-related activities by individual scientists who have shown the potential to achieve excellence, by national standards, within a five-year project period.

In the five participating states, more than 150 scientists and engineers are getting support to develop their research capabilities. This means more time to conduct research, better equipment and support staff, and more access to recognized experts in their fields. Thirty-six percent of the funds support research projects in the mathematical and physical sciences, 29 percent in the biological and behavioral sciences, 25 percent in atmospheric and earth sciences, and 11 percent in engineering.

The program in Arkansas is concentrated at the University of Arkansas at Fayetteville and the medical sciences campus in Little Rock. It supports emerging areas in molecular structure, laser physics, aquatic ecology, neurobiology, and genetics. Additionally, four scientists at smaller schools are supported in chemistry, biochemistry, and cell biology. Program emphasis is on upgrading equipment and technical support for research.

In Maine, the program focuses on marine and earth sciences. The University of Maine at Orono and the Bigelow Laboratory for Ocean Sciences have joined forces to strengthen their capability to study nutrient regeneration in the Gulf of Maine. In earth sciences the prime effort is on understanding the eastern segment of the Appalachian Orogen.

In Montana, 31 individual researchers, considered to have the greatest potential to become competitive on a national level, were selected from across the state. Research and faculty-development activities in 11 disciplines are being funded. Montana State

University and the University of Montana are the principal institutions involved; one project is underway at Montana Tech.

Awards in South Carolina are to improve (1) thermal science, bioengineering, environmental engineering, and mathematics at Clemson University; (2) physics, chemistry, mathematics, and social and behavioral sciences at the University of South Carolina; and (3) statistics at the Medical University of South Carolina. Funds are being used for faculty-release time, equipment, graduate-student stipends, and salaries for new faculty.

West Virginia is focusing on 20 young scientists and engineers in 8 strong departments. The funds are for increased release time, graduate student and postdoctoral support, and equipment to increase the research productivity of targeted faculty. The prime institution is West Virginia University, but one project at Marshall University is also being supported.

Honorary Awards

This NSF activity recognizes outstanding persons, based on their scientific, engineering, and technological contributions to the nation through research and public service.

Postdoctoral fellowships

The objective of this program is to provide up to an additional year of capstone training for a limited number of U.S. citizens who have held a Ph.D. in science or engineering for less than five years. Fellowships are awarded to individuals who are successful in a national merit competition; they may be used at each Fellow's chosen institution.

Competition for the limited number of these fellowships is very keen. In the year just completed, 950 eligible individuals applied for the 50 available fellowships. Each award includes an annual stipend of up to $13,800, some travel money if needed, an allowance to the host institution, and a small discretionary fund to the Fellow. A typical award amount is $15,400.

Applicants compete on the basis of ability, and support is distributed across all fields of science and engineering. A few examples of the work being done by Fellows are as follows:

- It has been shown that bone tissues are formed by deposits of calcium and phosphate salts in association with membranes. Because the resulting bone makes the membrane inaccessible, a study of the process at this level has been difficult. Now it appears that a proteolipid, a complex protein and fat molecule, may be involved and that a similar proteolipid also occurs in bacterial membranes.

  One Fellow plans to study the role of this particular molecule in relation to others in the bacterial membrane, in hopes of determining exactly which components are needed for mineral deposits to occur. She plans to construct artificial membranes that incorporate the proteolipid, in order to study its functions in detail. A better understanding of mineral deposition in bone could lead to improved treatment of skeletal disorders in the future.

- A major scientific effort is under way to develop alternative methods for producing fuels, plastics, and other chemical feedstocks. At present, crude oil, much of it from foreign sources, serves as the raw material for most of the processes to make these products. However, it may be possible to alter this situation in the future. The United States has a very large reserve of coal, and the conversion of coal to a mixture of the gases carbon dioxide and hydrogen is well within current technology. Methods for converting carbon dioxide and hydrogen mixtures to other valuable chemicals are also known, but the processes are not very efficient.

  More basic research on the nature and control of such conversion reactions is required if we are to make practical use of coal instead of crude oil as the raw material for products. One of this year's Fellows will be working on a new approach to these conversion reactions, hoping to identify a more efficient system leading to less reliance on imported crude oil.

- Among several long-standing problems in physics are the quantization of gravity and development of a unified description of the fundamental laws of physics. A new approach, called super symmetry, seems to hold some promise of helping to solve these problems.

  One common difficulty in reaching a solution is that forces calculated for very short distances between particles go to infinity, thus making meaningless the hypothesis being tested. By using the notions of super symmetry, however, researchers have found that some of the infinities cancel out each other. One of the Fellows selected this year hopes to extend this work to show that all of the infinities can be cancelled from the calculations. If he is successful, understanding of the physical laws governing nature could be advanced considerably, perhaps leading ultimately to solution of the quantization of gravity and unification-theory problems.

Alan T. Waterman Award

This award recognizes an outstanding young person in the forefront of science. In addition to a medal, the recipient receives a grant of up to $50,000 per year for up to three years.

Candidates for the award must be United States citizens 35 years of age or younger, or not more than 5 years beyond receipt of the Ph.D. degree in December 31 of the year they are nominated. Emphasis is on a candidate's record of completed, high-quality, innovative research—work that shows outstanding capability and exceptional promise for making significant achievements in the future.

There have been six recipients of the Waterman Award to date: two mathematicians, two physicists, one paleogeologist, and one chemist. The sixth recipient, W. Clark Still, Jr., of Columbia University, was honored in 1981 for research leading to control of the three-dimensional arrangements of atoms in large molecules.

Still's field of study is synthetic organic chemistry—specifically, methodology and its application to the construction of complex organic molecules. A desire to explore, understand, and manipulate the relative spatial configuration of atoms in molecules underlies his experimental studies. Most recently, his research group has been involved in developing a powerful new method to predict and control three-dimensional molecular structures using flexible chains of atoms.

Still's most recent work will give chemists a significant and fresh methodological approach, one that should aid the preparation of complex organic substances useful in a variety of fields. For example, his syn-

Alan T. Waterman Award winner. W. Clark Still, associate professor of chemistry at Columbia University, is the sixth recipient of this annual Foundation award.

thesis of the sex attractant of the American cockroach may allow control of that pest without the use of contaminating toxic pesticides.

NSF Planning and Evaluation

Long-range planning is a cyclical process that develops, collects, and uses information on the agency's objectives, structure, current activities, constraints, and mandates. This information enables the Foundation to set priorities, plan program activity, identify staff and support needs, and resolve major policy issues.

To supplement the extensive analysis done by in-house staff, the program supports a small number of extramural studies. In 1981 these studies focused on the following areas:

- Research price indexes in different academic disciplines, to promote understanding of the effects of inflation on research.
- The relationship between the Graduate Record Examination and advanced tests and NSF fellowship populations.
- Carbon dioxide in the atmosphere.
- Storage and handling of hazardous materials.
- Doctoral manpower in the sciences.
- A thesaurus for research proposals.
- The role and character of instrumentation in highly cited, published research in five science and engineering disciplines.
- Early identification of emerging fields of scientific inquiry.

Policy issues in the funding and performance of scientific activities are of continuing concern to NSF. Examples of such issues include the allocation of support among research areas; the way science and engineering relate to achieving national goals; more effective mechanisms to support science and engineering; the economic and social consequences of that support; ways to develop the nation's technology potential; and the opportunities for, and constraints on, the development of technical fields.

Evaluation studies provide the NSF director with information on the effectiveness of major NSF programs and the integrity of the award process. 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 but often carried out by contractors.

In September 1980, the Senate Appropriations Committee directed NSF "to secure a third party to develop a methodology for postresearch evaluation of scientific research endeavors." In response, NSF contracted with the National Academy of Sciences, as suggested by the Senate report, to do the study. An interim report to be submitted to the appropriations committee was completed October 1, 1981.

In addition, three other studies have been started in the past year and are nearing completion:

- The relationship between the quality of research output and the type of research (theoretical, empirical, facilitative, original, or derivative).
- The geographic distribution of NSF support.
- The link between patents and completed NSF research in chemistry.

Appendix A

National Science Board Members and NSF Staff

NATIONAL SCIENCE BOARD

Terms Expire May 10, 1982

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Terms Expire May 10, 1984

Lewis M. Branscomb (*Chairman*, National Science Board), *Vice-President* and *Chief Scientist*, International Business Machines, Inc., Armonk, New York

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Terms Expire May 10, 1986

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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

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Vernice Anderson, *Executive Secretary*, National Science Board, National Science Foundation

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- *Director (Acting), Division of Science Education Resources Improvement,* Terence L. Porter
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- *Director, Division of Financial and Administrative Management,* Kenneth B. Foster

Appendix B

Financial Report for Fiscal Year 1981

(In Thousands of Dollars)

Research and Related Activities Appropriation
Fund Availability

Fiscal year 1981 appropriation	$992,659	
Rescinded (Public Law 97-12)	-46,000	
Fiscal year 1981 appropriation adjusted		$946,659
Fiscal year 1980 deferrals available in fiscal year 1981	$16,000	
Unobligated balance brought forward	1,572	
Adjustments to prior year accounts	4,025	
Fiscal year 1981 availability		968,256

Obligations

Mathematical and Physical Sciences:		
Mathematical Sciences	$28,270	
Computer Research	22,334	
Physics	72,090	
Chemistry	57,623	
Materials Research	76,167	
Subtotal, Mathematical and Physical Sciences		$256,484
Engineering:		
Electrical, Computer, and Systems Engineering	$23,426	
Chemical and Process Engineering	18,454	
Civil and Environmental Engineering	28,461	
Mechanical Engineering and Applied Mechanics	16,006	
Subtotal, Engineering		$86,347
Biological, Behavioral, and Social Sciences:		
Physiology, Cellular and Molecular Biology	$78,234	
Behavioral and Neural Sciences	35,256	
Social and Economic Sciences	25,096	
Environmental Biology	41,052	
Information Science and Technology	5,944	
Subtotal, Biological, Behavioral, and Social Sciences		$185,582

SOURCES: Fiscal Year 1983 Supplementary Budget Schedules, Fiscal Year 1983 Budget to Congress, and NSF accounting records

Astronomical, Atmospheric, Earth, and Ocean Sciences:		
Astronomical Sciences	$58,376	
Atmospheric Sciences	69,269	
Earth Sciences	27,861	
Ocean Sciences	74,972	
Arctic Research Program	5,813	
Subtotal, Astronomical, Atmospheric, Earth, and Ocean Sciences		$236,291
U.S. Antarctic Program		$67,455
Ocean Drilling Programs		$22,000
Scientific, Technological, and International Affairs:		
Industrial Science and Technological Innovation	$17,063	
Intergovernmental and Public-Service Science and Technology	2,499[1]	
International Cooperative Scientific Activities	10,074	
Policy Research and Analysis	4,414[1]	
Science Resources Studies	3,095	
Subtotal, Scientific, Technological, and International Affairs		$37,145
Cross-Directorate Programs:		
Research Facilities and Instrumentation Programs	$6,152	
Other Programs	10,456	
Subtotal, Cross-Directorate Programs		$16,608
Program Development and Management		$59,207
Subtotal, obligations		$967,119
Unobligated balance carried forward		$1,014
Unobligated balance lapsing		$123
Total, fiscal year 1981 availability for Research and Related Activities		$968,256

Science and Engineering Education Activities Appropriation Fund Availability

Fiscal year 1981 appropriation	$83,200	
Rescinded (Public Law 97-12)	-10,000	
Reduction pursuant to Public Law 96-526	-2,496	
Fiscal year 1981 availability		$70,704

Obligations

Science and Engineering Education Activities:		
Scientific Personnel Improvement	$33,370	
Science Education Resources Improvement	17,833	
Science Education Development and Research	10,870	
Science Education Communication	8,591[2]	
Subtotal, obligations		$70,664
Unobligated balance lapsing		$40
Total, fiscal year 1981 availability for Science and Engineering Education Activities		$70,704

[1] Funds for Science for Citizens and Ethics and Values in Science and Technology came under the SEE appropriation in FY 1981.

[2] Includes $3,065,691 for programs administered by STIA in FY 1981

Special Foreign Currency Appropriation

Fund Availability

Fiscal year 1981 appropriation	$5,000	
Unobligated balance brought forward	640	
Adjustment to prior year accounts	44	
Fiscal year 1981 availability		$5,684

Obligations

Special Foreign Currency Program:		
Research and Related Activities	$2,945	
Science Information	1,050	
Subtotal, obligations		$3,995
Unobligated balance carried forward		1,550
Unobligated balance lapsing		139
Total, fiscal year 1981 availability for Special Foreign Currency Program		$5,684

Trust Fund

Fund Availability

Unobligated balance brought forward	$3,016	
Receipts from nonfederal sources	8,664	
Adjustment to prior year accounts	1,369	
Fiscal year 1981 availability		$13,049

Obligations

Ocean Drilling Programs	$8,736	
Gifts and Donations	6	
Subtotal, obligations		$8,742
Unobligated balance carried forward		$4,307
Total, fiscal year 1981 availability for Trust Fund		$13,049

Appendix C

Patents and Inventions Resulting from Activities Supported by the National Science Foundation

During fiscal year 1981, the Foundation received 91 invention disclosures and made rights determinations on 82 of those inventions. The determinations, made according to NSF patent regulations, included decisions to dedicate the invention to the public through publication in 10 cases, to permit retention of rights by the grantee or inventor in 70 instances, and to transfer rights to other government agencies in 2 cases. The Foundation received licenses under 38 patent applications filed by grantees and contractors who had been allowed to retain principal rights in their inventions.

The Bayh-Dole Act (section 6 of P.L. 96-517, 35 U.S.C. section 200 *et seq.*) was signed by President Carter on 12 December 1980. It allows small business firms and nonprofit organizations, including universities, to retain principal patent rights to inventions made with federal support. The Bayh-Dole Act affects most grants and contracts awarded after 1 July 1981, but no invention disclosures under such awards were received in fiscal year 1981.

Because the Bayh-Dole Act eliminates the need for institutional patent agreements, NSF entered into no new agreements of this type in fiscal year 1981.

On 16 June 1981, the Foundation's General Counsel determined that NSF could not legally exercise a "nonuse march-in" right on U.S. patent number 3,902,994, "High Gradient Magnetic Separator with Continuously Moving Matrix," held by the Massachusetts Institute of Technology. He concluded that MIT had made the patent available for licensing on reasonable terms.

The following patents were issued for fiscal year 1981:

Number	Title	Institutions
4,128,554	Process for the Preparation of Carboxylic Acid Amides from Organic Halides	University of Delaware
4,189,070	Reaction Injection Molding Machine	University of Minnesota
4,189,677	Demodulator Unit for Spread Spectrum Apparatus Utilized in a Cellular Mobile Communication System	Purdue Research Foundation
4,193,031	Method of Signal Transmission and Reception Utilizing Wideband Signals	Purdue Research Foundation
4,216,065	Bio-Selective Electrode Probes Using Tissue Slices	University of Delaware
4,222,115	Spread Spectrum Apparatus for Cellular Communication Systems	Purdue Research Foundation
4,223,049	Superficially Mixed Metal Oxide Electrodes	Research Triangle Institute
4,224,795	Method for Converting Heat Energy to Mechanical Energy with Monochlorotetrafluoroethane	Allied Chemical Corporation
4,226,845	Water Gas Shift Reaction and in the Hydroformylation and Hydrohydroformylation Reactions	SRI International
4,228,338	Process for Implanting Radioactive Metal on a Substrate	Massachusetts Institute of Technology
4,229,231	Method of Forming a Laminated Ribbon Structure	Massachusetts Institute of Technology
4,230,828	Polymer-Bound Multidentate Complexes	University of Illinois Foundation
4,231,947	Tantalum and Niobium Catalysts or Catalyst Precursors	Massachusetts Institute of Technology
4,237,023	Aqueous Heat-Storage Compositions Containing Fumed Silicon Dioxide and Having Prolonged Heat-Storage Efficiencies	Massachusetts Institute of Technology
4,237,224	Process for Producing Biologically Functional Molecular Chimeras	Leland Stanford, Jr., University
4,242,611	Methods and Apparatus for Providing Ultra-Stable Frequency Standards and Clocks	University of Rochester
4,245,131	Dimerization of Olefins Using Tantalum and Niobium Catalysts	Massachusetts Institute of Technology
4,248,791	25-Hydroxy-26,26,27,27,27-Hexafluorocholecalciferol	Wisconsin Alumni Research Foundation
4,252,573	Collector Grid for CDS/CUS Photovoltaic Cells	University of Delaware
4,254,002	Tough Plastics Based on Castor Oil Elastomer-Reinforced Vinyl Polymers	L. H. Sperling, J. A. Manson, and N. Devia-Manjarres

4,254,045	1 -Hydroxy-2 -Fluorocholecalciferol	Wisconsin Alumni Research Foundation
4,261,815	Magnetic Separator and Method	Massachusetts Institute of Technology
4,264,750	Process for Fluorinating Polymers	Massachusetts Institute of Technology
4,272,336	Method and Apparatus for Forming Nitric Oxide from Ammonia	Massachusetts Institute of Technology
4,275,265	Complete Substitution Permutation Enciphering and Deciphering Circuit	Wisconsin Alumni Research Foundation
4,276,195	Converting Homogeneous to Heterogeneous Catalysts	Iowa State University
4,281,119	Cryogenically Controlled Direct Fluorination Process, Apparatus and Products Resulting Therefrom	Massachusetts Institute of Technology
4,282,034	Amorphous Metal Structures and Method	Wisconsin Alumni Research Foundation
4,286,026	Article for Implanting Radioactive Metal on a Substrate	Massachusetts Institute of Technology

Appendix D

Advisory Committees for Fiscal Year 1981

OFFICE OF THE DIRECTOR

The Alan T. Waterman Award Committee

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Stanford University

D. Allan Bromley
Henry Ford II Professor
Wright Nuclear Structure Laboratory
Yale University

Jewel Plummer Cobb
Dean and Professor of Biology
Douglass College
Rutgers-The State University of New Jersey

Mildred S. Dresselhaus
Professor of Electrical Engineering
Massachusetts Institute of Technology

William E. Gordon
Provost and Vice President
Rice University

David S. Hogness
Professor of Biochemistry
Stanford University School of Medicine

Mark Kac
Professor of Mathematics
University of Southern California, Los Angeles

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

Benjamin Widom
Professor of Chemistry
Cornell University

Ex Officio

Lewis M. Branscomb
Chairman
National Science Board

Courtland D. Perkins
President
National Academy of Engineering

Frank Press
President
National Academy of Sciences

John B. Slaughter
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