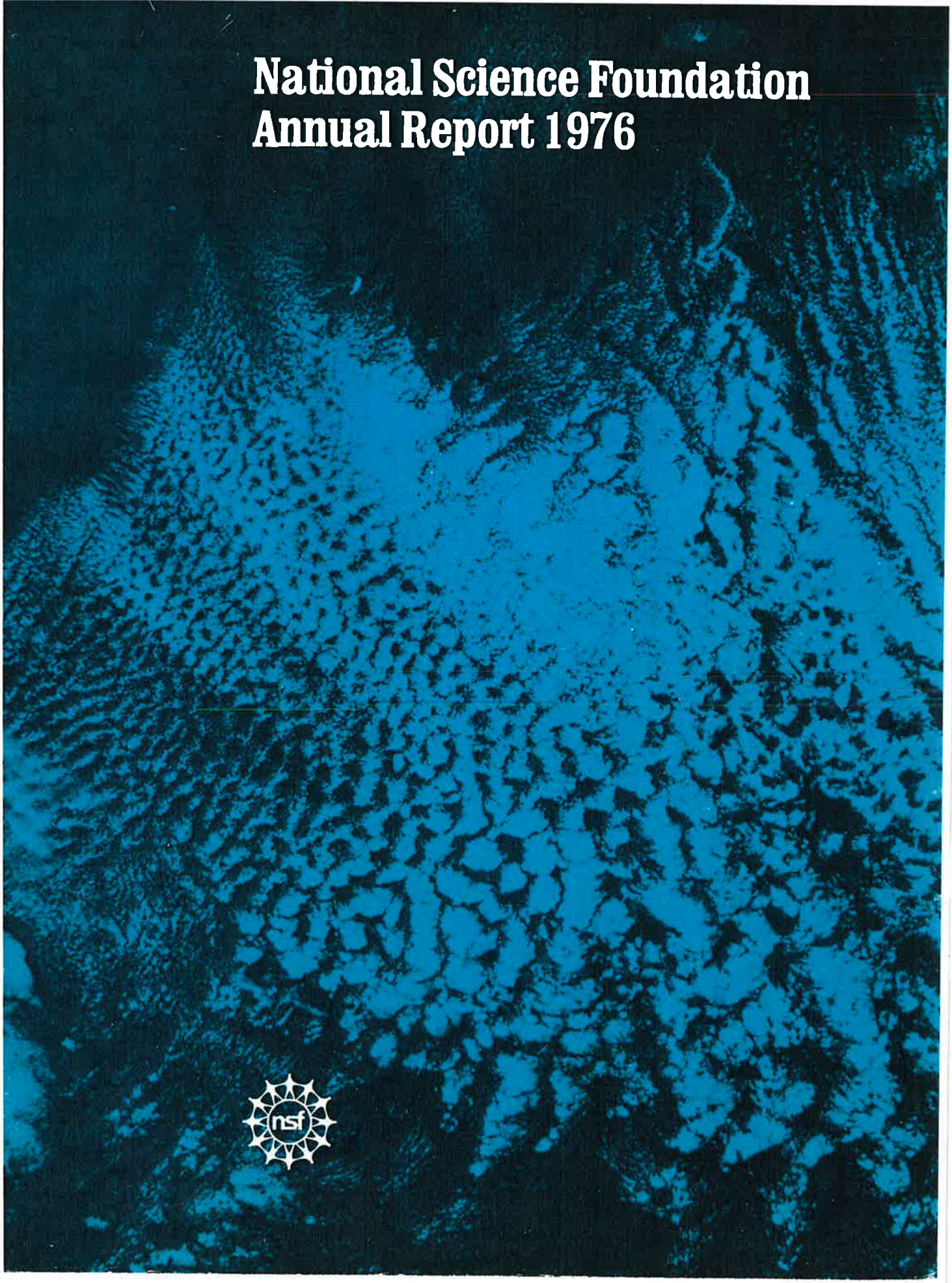
National Science Foundation Annual Report 1976



National Science Foundation

Twenty-Sixth Annual Report for Fiscal Year 1976

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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 1976 of the National Science Foundation for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,

RICHARD C. ATKINSON
Acting Director, National Science Foundation

The Honorable
The President of the United States

Contents

The Frontier is Still Endless

It is with pride that I tender the annual report to the President of the activities of the National Science Foundation for the year 1976. I propose to discuss some of the specific research efforts supported by the Foundation as well as the recent progress of American scientific research in general, emphasizing the kind of basic inquiry which it is the primary duty of the Foundation to foster. In addition, I shall comment on some of the larger issues of science policy and suggest approaches that may assure the continued health and strength of American scientific research in the future.

This report sets forth a broad record of the Foundation's support of research in areas ranging from the most fundamental investigation of quantum properties of matter to applied research dealing with natural disasters, environmental quality, and weather and climate. It also discusses the Foundation's important role in science education, science manpower analysis, and science policy studies.

Advances during 1976 again demonstrate that we have barely scratched the surface of scientific discovery. The recent successful construction of an entirely manmade gene and related results in biochemistry are leading us to new insights into such prosaic but vital life processes as the photosynthetic fixation of carbon dioxide and water by plants into carbohydrates and proteins for human nutrition and the natural fixation of nitrogen compounds for plant use by one-celled organisms.

We have recorded advances in abstract areas like mathematics that permit the use of computing machines in more powerful and subtle ways, as well as advances in the electrical sciences which may lead to the development of practical devices for communications in the infrared and optical frequencies. There is evidence to suggest that areas of materials research may be leading to a new range of low-cost materials with remarkable properties—for example, a treatment of graphite giving it an electrical conductivity 50 percent greater than copper. We are realizing similar advances in understanding how catalysts stimulate chemical reactions of importance to major industrial processes, and the exact way that fatigue impairs the strength of metals subject to cyclic loads.

In the behavioral and neural sciences, an anthropologist supported by the Foundation and the National Geographic Society has traced man's origins to 3½ million years in the past; other scientists have gained important insights into the role of early experience in the development of "wiring" the adult brain, in the very early development of linguistic concepts in primates and young children, and in the growth and self-repair processes of the brain. These latter developments have important implications for dealing with deprivation and learning disabilities in children and ultimately, perhaps, in coping with brain damage itself.

A similar problem is also the basis for important work in the research applications area. There, a computerized neurological measuring technique shows promise for a simple screening

test to assist in the early identification and remediation of children who are likely to develop learning problems. The computer also figures prominently in another important result in research applications—methods to improve the earthquake-resistance of structures; computer programs developed in the course of research on soil responses to earthquakes are now in wide use by engineering firms involved in structural design and are being incorporated into building codes.

Several new activities intended to help the Nation's educational institutions keep pace with these rapid advances in science began in 1976, including one aimed primarily at improving instructional programs at 2- and 4-year colleges. NSF also began a program to make it easier and more productive for private citizens to take part in public policy decisions having strong science and technology components.

Internationally, scientific inquiry is moving ahead today with a renewed vigor and fruitfulness, and American investigators are playing a paramount role in this work. This situation is particularly heartening because it follows a period of severe funding difficulties and even a sense of pessimism within the scientific community itself about the opportunity which science might have to contribute to America's future. Not all of the constraints and problems in the conduct of U.S. science are solved by any means, but I believe solutions for such difficulties as we face lie well within the reach of science policy.

The Role of New Knowledge in Economic Growth

Some regard modern science as the intellectual edifice of the Age of Reason, an abstract equivalent of the majestic cathedrals which express the creative impulse of the medieval period. And indeed, individual scientists often derive much the same sort of aesthetic pleasure and excitement in contributing details to this structure of knowledge as did the carpenters and stonemasons of the earlier period.

However, the systematic gathering of new scientific knowledge is not solely an end in itself, even if the individual scientist has no conception of the ultimate practical significance of his work. Acquisition of new knowledge is a form of economic investment, with an importance equal to land, labor, and capital, the more traditional components of production and investment.

This investment aspect of scientific inquiry is recognized by the economist, Edward F. Denison, in his major study, "Accounting for United States Economic Growth 1929-1969." Denison found that "advances in knowledge" have been of major importance in national economic growth, particularly in the comparatively recent period of U.S. history.

He found that advances in knowledge were responsible for about 31 percent of the potential growth rate in national income over the entire 40-year period covered by his study, and that this contribution edged upward to about 34 percent during the latter half of the period when there was a marked expansion in the numbers of new scientists and a distinct acceleration in the pace of basic research activity. It is noteworthy that this postwar period has been characterized by a new awareness of the importance of scientific knowledge to the Nation's security and well-being, with the Government, for the first time, assuming a major role in the financial support of basic research in the universities and other institutions. It was this awareness that led to the formation of the National Science Foundation in 1950 and to its major role today in promoting and supporting basic scientific inquiry.

The Interaction of Basic and Goal-Related Research

Most of us can readily appreciate how specific technological advances like the automobile, the

airplane, electronic communications, and even the hand-held calculator have increased our economic productivity and generally our national well-being. What is not generally appreciated is that these and virtually all other major technological advances of the modern era are a culmination of a remarkable diversity of prior advances in knowledge in areas often entirely unrelated to one another.

The Foundation has sponsored a number of "trace" studies to examine in some depth the lineal development of important technological developments. In one study performed by the IIT Research Institute, the critical events leading to the electron microscope, the video tape recorder, the oral contraceptive, and other technological achievements were identified and examined in detail. What the investigators found was that, on the average, about 70 percent of all the critical events necessary to realize a major technological development flow from scientific inquiry of the most basic and nondirected kind. This generalized precursor activity tends to peak 20 to 30 years before the appearance of the technological innovation itself, long before the individual investigators or, in many cases, their sponsors, can have any idea of the practical consequences their work may lead to.

Only quite late in the gestation of a major technological innovation, following some act of "invention," does the scientific work begin to take on an applied character, in which the inquiries are aimed at achieving a synthesis of the prior knowledge in the form of a specific new capability or product. This applied research and development contributes about 30 percent of the critical knowledge necessary for a major innovation, and the greatest amount of it tends to be done in the decade immediately preceding the innovation.

A similar interaction between basic and applied research has been found in the biomedical sciences, despite the fact that biology is understandably more focused on specific human needs than are most of our other scientific endeavors. In an important study of ten major advances in cardiovascular and pulmonary medicine and surgery over the past 30 years, Julius H. Comroe, Jr., and the late Robert D. Dripps *(Science,* Vol. 192, p. 105) found that an average of 41 percent of all the critical events necessary for major advances like open heart surgery or effective drug treatment of hypertension flowed from prior work of a non-clinical nature—that is, research that wasn't performed with the expectation that it had any direct or indirect bearing on a clinical disorder of humans.

This interaction of basic and applied research gives us insight into the nature of technological innovation. It strikes me that we are dealing with a sort of intellectual riverine system. As the flow of ideas nears its terminus, it is a forceful and purposeful thing. But we cannot overlook the fact that this great river must rise in thousands and tens of thousands of creeks and brooks at the higher elevations and remotest limits of its drainage basin. It is the myriad contributions of the latter that give the river its ultimate force and, quite simply, this is why we must nurture these earliest sources if we are to safeguard the creative force of the entire process.

The Pace of Scientific Advance

In recent years a number of concerns have been expressed about whether the process of scientific discovery and innovation, with its potential for economic growth, can continue at the present rate. These issues intimately concern scientific advance itself, the process of discovery and innovation which has made post-Renaissance Western culture a unique phenomenon in human history.

In a series of lectures delivered at Yale University in 1959, and subsequently published in collected form *(Science Since Babylon,* Yale University Press, 1961), the science historian, Professor Derek J. de Solla Price, raised important questions about

the future of science. He observed that 80 to 90 percent of all the scientists who ever lived were alive at the time of his lectures, largely because of the exponential growth rate in the numbers of American scientists. He warned, correctly, that this exponential growth rate could not continue indefinitely, and he forecast that the growth of the force of trained scientists in the United States would become "saturated" within about 30 years. In fact, we now see a leveling-off in the numbers of trained scientists which our higher education system is now producing.

Professor de Solla Price went on to forecast a number of distinct ailments which would befall American science as the growth rate flattened. These include a relentless increase in narrow specializations in scientific disciplines, a decline in interdisciplinary cross-fertilization, "too many discoveries chasing too few workers," and a general decline in the quality of American science. History has yet to confirm or reject Professor de Solla Price's predictions, but so far the pace of important discovery continues to increase.

Since 1960 we have experienced the revolution in earth sciences called "plate tectonics." In a single, blinding stroke, this new theory of great, restless plates forming the outer skin of the Earth unified old and disparate disciplines like geology, oceanography, seismology, volcanology, and others. A similar revolution is under way today in the biological sciences, largely because of the increasing depth of our understanding of the role of nucleic acids in forming the genetic blueprints of all living organisms and our powerful new abilities to explore and manipulate complex cellular processes at unprecedented levels of sophistication.

New Tools to Amplify Scientific Investigative Power

While the opening of major new frontiers has contributed to sustaining the creative forces of modern science, at least as large a contribution has come from an array of powerful and sensitive new instruments and experimental techniques that amplify the investigative power of our scientists. These new instruments and techniques, many with origins in physics, have been especially helpful in chemistry and biology where they increase both the scope and speed of scientific measurement and analysis. The new instruments and techniques dramatize the fact that our progress in scientific disciplines need not be limited to the sheer numbers of trained scientific brains that we can mobilize to gather data and solve problems. This is most encouraging in a period when we see that the earlier rapid growth in our scientific manpower is leveling off. Let me mention some of these developments in somewhat greater detail:

Laser Photochemistry and Spectroscopy—The laser is unique in its ability to generate sharp, powerful pulses of highly coherent radiation at optical and near-optical wavelengths. Unlike the traditional Bunsen burner, whose heat excites molecular bonds indiscriminately, usually breaking the weakest ones first, certain types of lasers operating in the infrared can be tuned to specific chemical bonds within the molecule. This may make it feasible to deliver several quanta of energy to this bond, possibly causing it to disrupt, while weaker bonds are left intact. This raises the possibility that high-powered lasers will find major new roles for such tasks as the separation of heavy isotopes of elements like uranium as well as the selective synthesis of new molecular species and compounds beyond the reach of the reaction paths presently available to chemistry.

Computer Augmentation of Existing Instruments—The rapid spread of the minicomputer and microcomputer into the laboratory now enables scientists to achieve new levels of speed and sensitivity with their more conventional instruments, like nuclear magnetic resonance spectrometers. Computers, together with powerful mathematical pro-

grams, enable chemists to generate fast, accurate spectral measurements from exceedingly small samples of material. Mathematical techniques now make it possible to construct three-dimensional images to very high resolution in electron microscopy, and there has been a rapid development of instruments with small, built-in computers that allow essentially automatic operation.

Restriction Enzymes—In the biological revolution now under way, one of the most important advances has been the identification of an array of specialized proteins in bacteria—the restriction enzymes—which cleave strands of nucleic acids at highly specific points. The nucleic acid, DNA, encodes the genetic information that specifies the architecture and function of living organisms from viruses to man. The task of identifying the sequence of subunits in a DNA molecule of a single gene is greatly facilitated by the use of enzymes. Today a chain of 20 DNA subunits can be sequenced in a single afternoon. Only a few years ago, it took as long as 2 years to perform this task.

Molecular Cloning—Molecular biologists have recently found ways to transfer genetic material from one organism into an unrelated organism, where it may replicate and hopefully function in a normal manner. Experiments involving the use of such recombinant DNA material must be conducted in accord with guidelines set by the National Institutes of Health to minimize risks of untoward results. This technique offers new possibilities for exploring and manipulating the biochemistry of one-celled organisms at unprecedented levels of sophistication.

For example, if certain plasmids are used to transfer foreign DNA into the bacterium, *E. coli*, as many as 1,000 copies of the transferred DNA can be produced at each division of the bacterium. This process of "gene amplification" could lead to the inexpensive production of transferred genes with useful characteristics, such as the gene that specifies the production of the enzyme *nitrogenase*. This enzyme permits certain bacteria associated with some plants to incorporate free atmospheric nitrogen into organic molecules. This offers the possibility of transferring to cereal-producing plants the genes specifying the nitrogen-fixation capability, alleviating the plants of their dependence on costly chemical fertilizers to assure maximum growth and protein yield.

Many barriers must be surmounted before we can hope to tailor the genetic characteristics of plants and other organisms in directions which will improve man's welfare. Nevertheless, we can be optimistic that recombinant DNA and molecular cloning will lead in the relatively near future to new capabilities in biology. One of the often cited new possibilities is the insertion into *E. coli* of the gene from higher organisms controlling the synthesis of insulin and other important hormones. Currently, these hormones must be obtained through much more expensive methods and often in limited amounts. Utilization of the DNA recombinant methodology is likely to lead to increased availability of such hormones.

Some Constraints on U.S. Science

While the current health and strength of the American scientific enterprise is reassuring, I do not believe we should overlook certain areas of potential difficulty:

- First, we should be aware that one of the prime factors in the overall success of American science is its remarkable diversity. Not only are there many investigators in universities, nonprofit institutions, government, and industry attacking fundamental scientific problems from many different directions, but support for this activity has traditionally come from many sources.

In the post-World War II period, the Federal Government has become the dominant source of support for basic research. Yet in recent years there has been a tendency to narrow the scope of

basic research which can be conducted in or supported by certain elements of the Government, notably the Defense Department. We must ask ourselves, whether, in a period in which U.S. security depends overwhelmingly upon technological superiority, it is wise to inhibit the involvement of our defense establishment to the full flow of new ideas necessary to maintain this superiority. I am mindful that the Foundation has a major responsibility within the Government to support basic research, but I do not interpret this as an exclusive responsibility. U.S. science is strong because of its pluralistic character, and we must bear this in mind when we consider the need for multiple wellsprings of its support.

• Second, we must develop more realistic expectations about what can be achieved by large-scale research campaigns aimed at specific goals. Doubtless the success of the Manhattan Project of World War II and the Apollo lunar program have convinced many of our fellow citizens that highly organized operations of this type are the proper way to achieve spectacular results. Yet I fear that many of us lose sight of the fact that these successful projects enjoyed the good fortune of resting on a comprehensive knowledge base constructed by prior scientific research largely basic in character. Unfortunately, not all large-scale research campaigns have the same advantage, and we find that where the knowledge base is incomplete or defective in some respect, no amount of Federal commitment can achieve solutions without first obtaining the needed scientific understanding. We are experiencing current disappointment in the war on cancer, and this experience should give us pause before we embark on other large-scale programs of directed research, no matter how socially beneficial the objectives.

Having said this, I hasten to add that applied research is and must remain a vital component of our Federal science programs, particularly in the mission agencies like the Defense Department and NASA. Without it, we could hardly have superior weaponry or a Viking mission to Mars—and the latter, of course, has given us a magnificent opportunity to conduct basic research on our nearest planetary neighbor in space. One of the important activities of the Foundation is the RANN program—Research Applied to National Needs—and one of its prime objectives is to focus U.S. science resources on selected national problems. Through this program the Foundation started a promising solar energy research program in the early 1970's, well in advance of the oil crisis. The program demonstrated the feasibility of heating major public buildings with solar energy systems. This program was transferred to ERDA in fiscal year 1976 and now forms the core of that research effort. Both basic and applied research are necessary in a balanced effort and, indeed, each one nourishes and stimulates the other.

• Third, there is reason for increasing concern about the diminishing prospects of younger scientists for entry into the faculties of universities, which presently perform more than half of all U.S. basic research. The problem is complicated by demographic factors which will turn sharply negative for college and university enrollments in the 1980's and by the recent strong increase in the proportion of tenured scientists and engineers on university faculties. These circumstances threaten a virtual "lockout" in many disciplines and could, over the longer term, vitiate American scientific performance.

• Fourth, I believe we must continue our efforts to assure students the strongest possible education in the sciences. From a pedagogical standpoint, the courses that have been designed in recent years for instruction in mathematics and the sciences in the secondary schools are exciting and challenging. If they have a fault, it may be that they have been geared too narrowly to the needs of students with the specialist's interest in these subjects. While such students

have received a marvelous education, other secondary students whose primary interests lie elsewhere may not have been so well served. Because one of our clear goals is a scientifically enlightened citizenry, competent to deal with important policy issues in science and technology, I believe we must give serious consideration to broadening and extending our science education programs at the secondary level, as we have already done at the elementary level.

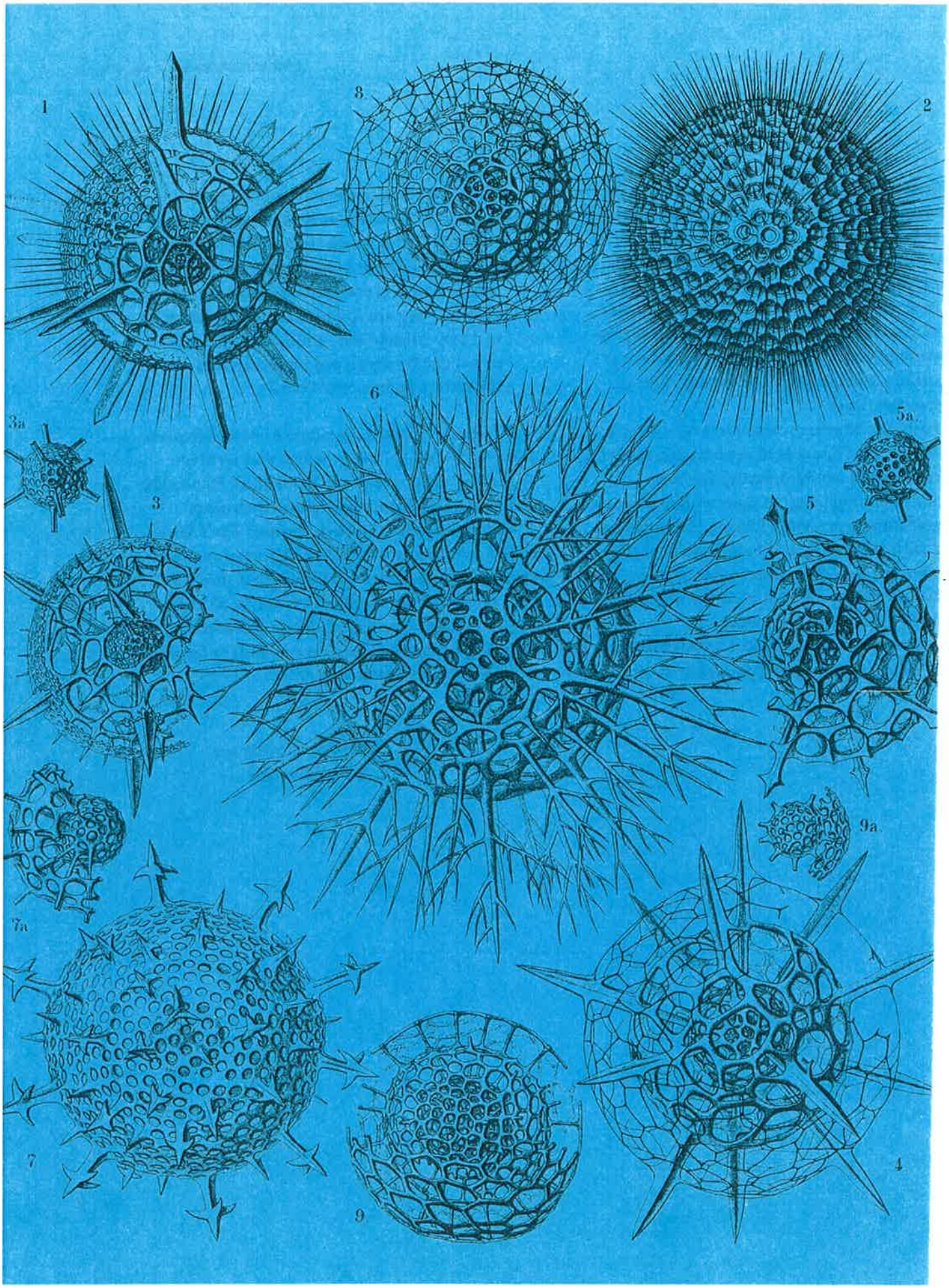
- Fifth, the time has come for a far-ranging and detailed study to assist in determining where the Nation should set its priorities for basic research in the remaining 20 years of this century. The Foundation is presently looking into ways to proceed with this study, and I am hopeful that its completion will give us a clearer view of our scientific horizons and a firm basis for making critical policy choices in the future.

Vannevar Bush, the principal architect of our scientific effort in World War II, wrote in 1945:

> "Basic research leads to new knowledge. It provides scientific capital. It creates the funds from which the practical application of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science."

Those words are contained in Bush's Report, *Science—The Endless Frontier,* which was written at the request of President Franklin D. Roosevelt, in a time of high optimism about the role of science in America's postwar future. The record shows that Bush's confidence in science was well-placed. Moreover, I am confident that the frontiers of science are as endless today as 30 years ago and that science will continue to exert a dynamic and positive force in our society for the next 30 years and long beyond.

Richard C. Atkinson
Acting Director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Mathematical and Physical Sciences, and Engineering

1

The Mathematical and Physical Sciences, and Engineering are mature disciplines in the sense that they have developed a large body of firmly established experimental results knit together with general, quantitative theories. The whole structure has attained a remarkable predictive and manipulative capability which is exhibited in technological artifacts ranging from electric power stations and suspension bridges to transistorized radios; and from synthetic fibers to satellites. Yet there remain a great many areas in which understanding is still incomplete, partly because our new knowledge leads us to ask increasingly intelligent questions about the processes of the physical universe. Answers to these questions in turn (as well as the practical applications that may eventually follow) often require—and may have to wait for—new tools and new mathematical techniques.

For example, the nature of chemical species at surfaces is an important, fundamental, and unanswered question in understanding surface catalysis and enzyme mechanisms. The energy transfer between or within molecules is just beginning to be understood. In mathematics, techniques are now being utilized to study the propagation of nonlinear waves, including gravity waves and long surface waves in the oceans and the atmosphere. In physics we still search for the ultimate fundamental particles and for an understanding of gravity and the role it plays in determining the evolution, structure, and fate of the universe. In engineering, by what processes are solid sediments transported in water or particulates diffused from smokestacks? What are the limits for communications use of the vast channel capacity inherent in the visible spectrum as an extension of the radio spectrum? Materials scientists continue to search for the underlying causes of cracks that propagate and cause failure in metallic, ceramic, and polymeric materials in structural applications. And computer scientists search for new design principles that will lead to yet another generation of computing capability.

NSF's 45 programs in Mathematical and Physical Sciences, and Engineering operate primarily through support of individual research projects. The objective of this support is to provide an orderly development of systematic knowledge and understanding of natural phenomena. While most of the new knowledge is expected to prove useful in the long run, and some fraction of it may prove useful immediately, for the most part it is supported with no precommitment to a particular application. One great virtue of basic research is that it provides scope for the examination of phenomena from all possible points of view and for the recognition of the multiple and diverse applications. Many times science turns a difficulty at one point into an advantage at another, so that seemingly insuperable difficulties are outflanked by progress made in what at first sight appeared to be wholly unrelated areas.

Proposals submitted to these programs are generated by the intellectual initiative of scientists and engineers. In this sense the proposals are characterized as unsolicited. In

Table 1
Mathematical and Physical Sciences, and Engineering
Fiscal Years 1974, 1975, 1976
and Transition Quarter (July 1-Sept. 30, 1976)

(Dollars in Millions)

	Fiscal Year 1974		Fiscal Year 1975		Fiscal Year 1976		Transition Quarter	
	Number	Amount	Number	Amount	Number	Amount	Number	Amount
Chemistry	722	$ 26.64	828	$ 32.73	832	$ 34.65	220	$ 9.25
Engineering	716	28.09	710	34.26	691	35.85	188	9.21
Physics	314	36.73	328	42.20	354	45.17	82	10.56
Materials Research	472	35.56	524	43.53	609	46.12	147	8.28
Mathematical Sciences	739	14.50	842	16.46	838	17.26	104	4.70
Computer Research	164	9.76	193	11.78	216	13.22	51	2.98
Total	**3,127**	**$151.28**	**3,425**	**$180.96**	**3,540**	**$192.27**	**792**	**$44.98**

addition to the research projects, conferences and workshops are supported to define and focus attention on various research opportunities. Most proposals are submitted by academic institutions in the United States on behalf of research workers who wish to answer a specific scientific question or questions. Despite the great number and diversity of proposals, they are individually evaluated by people capable of understanding the intent of the research and the significance of the expected results. The review process brings to bear critical minds to judge the merit of the project that has been proposed. In this process some 15,000 scientists from all parts of the country and abroad were called upon in fiscal year 1976 to evaluate proposals for the Mathematical and Physical Sciences, and Engineering programs. A great many of the reviewers were from universities, but many were also called upon from Government and industrial laboratories and from nonprofit research organizations as well. The successful proposals provided support for the research efforts of more than 6,700 scientists and engineers. In addition, more than 4,200 graduate students have an opportunity for experience under the direction of some of the Nation's best researchers, a beneficial byproduct of the quest for new knowledge.

Physics

Physics is that branch of science which studies the fundamental laws governing matter and energy over a complete range of scale, from the most elementary constituents of matter (quarks and leptons) to the largest aggregation (the universe). The aim is a unified interpretation of all phenomena into a single, self-consistent explanation based on detailed knowledge of the basic forces acting on particles. Physics has continuously contributed new fundamental understanding of matter at all levels of aggregation to the other fields of science, and has provided the underpinnings to many of our current advances in science and technology.

NSF physics programs contribute to increased understanding of these phenomena by supporting high quality research projects in certain subfields of physics. Four programs support experimental work—elementary particle physics; intermediate energy physics; nuclear physics; and atomic, molecular, and plasma physics. The theoretical physics program supports investigations on the theoretical framework within which the experimental results are interpreted. A sixth category, gravitational physics, supports theoretical and experimental studies on gravity, the weakest of all known forces in the universe.

It has been known for decades that all matter is made up of basic constituents such as the proton, neutron, and electron, which we refer to as the "elementary particles." New discoveries are adding considerable weight to the theory that the "elementary" particles are not the ultimate building blocks, but are in turn made up of more basic pointlike constituents called "quarks." Pursuing this idea, NSF-supported *theorists* at Harvard and at Cornell have compared recently discovered particles to states of an atom with different configurations of its constituent electrons. They have predicted that, like an atom, the new particles should turn into still further new particles (that is, new configurations of the constituents) with the emission of energy in the form of electromagnetic radiation. During the summer of 1975, laboratories in the United States and in Germany reported results which indicate that at least three of the predicted secondary particles do indeed exist.

In addition, the Foundation's program has contributed significantly to knowledge of these new particles through an active program of research conducted by a number of *experimental* groups. At Cornell, groups have measured the rate of production of the new particles in photon-induced processes near the threshold energy. At the Fermi National Accelerator Laboratory, a Columbia University group has conducted similar studies at higher photon energies. NSF-funded groups from Columbia, Chicago, Northeastern, Washington, and Michigan State, along with Energy Research and Development Administration-supported groups, have measured the production rate of the new particles using strongly interacting probes such as pi mesons and protons, and have noted that pi mesons appear to be substantially more effective than protons in producing these new states. The results of these experiments are essential inputs to the theoretical effort.

The quark structure of neutrons and protons (each is assumed to be composed of three quarks) has also been shown to be important in understanding nuclei and nuclear processes. An NSF-supported American University-Stanford-Bonn collaboration has found that scattering of high-energy electrons from deuterium is much more simply understood in terms of a six-quark structure of the deuteron than in terms of the usual neutron-proton structure, with the binding force produced by meson exchange. In work carried out in England, it has been shown that a careful study of nuclear beta-decay permits a deter-

mination of the electrical charges carried by these quarks and thus distinguishes among different theories of the neutron and proton substructure.

In the area of weak interactions, precise experiments are testing our understanding of nuclear beta-decay at high levels of precision. A group at Princeton has used a cyclotron to prepare excited ^{19}Ne (neon) nuclei which are then fed into an atomic beam apparatus which orients their spins. The nuclei then beta-decay and the asymmetry of the decay products with respect to the spin direction is measured as a function of beta energy. The results indicate that the present theory of nuclear beta decay, which has long been accepted, may require modification.

The great extension of astronomical observation brought about by the application of technology in the early 1960's led to a revival of interest in general relativity, because it seemed that the new objects being discovered (such as quasars, pulsars, and compact X-ray sources) were radiating more energy than could be supplied by nuclear processes. The only possible source of this energy appears to be gravity, which implies that the objects must by very concentrated and must have very intense gravitational fields, fields so strong that they would significantly affect the propagation of light. Since 1970, theoretical research has shown that a gravitationally collapsing body would produce a black hole. It has been suggested that the hidden properties of a black hole could be completely summarized by its entropy. A major difficulty with this suggestion was that it led to inconsistencies, unless black holes emitted thermal radiation at temperatures above zero. This is impossible according to classical general relativity, since the classical theory predicts that black holes should not be visible to an external observer.

S.W. Hawking of the California Institute of Technology discovered, however, that quantum effects would cause black holes to emit thermal radiation with a temperature above zero, and that the final stage in the life of a black hole would produce a tremendous explosion, with an accompanying burst of high energy gamma rays. Hawking, L.E. Parker (University of Wisconsin), and R.M. Wald (University of Chicago) have shown that the radiation coming off is like that emitted by any hot object in all senses, including the fact that different modes and different numbers of particles in the same mode are completely uncorrelated.

This year has seen much progress in small steps across the broad frontiers of physics. Of special note are the completion of a new cyclotron facility, the discovery of a particle confirming the existence of "charm," the possible discovery of new "superheavy elements" in nature, and the development of a new technique for mapping the energy levels in atoms and molecules.

Discovery of a Charmed Baryon

A team of physicists from Columbia, Fermilab, Illinois, and Hawaii has announced the discovery of a charmed baryon—a subatomic particle in the same family as protons and neutrons. The finding adds support to the view that hadronic matter—those subnuclear particles, such as the baryons, which interact via the "strong" nuclear force—is composed of basic constituents known as quarks. Until recently, the effects of only three types of quarks have manifested themselves; a fourth type of quark referred to as the "charmed quark" is required to explain the latest experiments. The "charm" that characterizes the new baryon is regarded as evidence that the fourth and "charmed" type of quark is indeed present. Though a baryon is still composed of three quarks, and a meson of two, we now know there are four possible types of which the combinations can be made.

The idea that hadronic matter is made of quarks was proposed in the early 1960's. To explain the particles that were appearing in the experiments of that time, three quarks were needed. The three-quark picture was used with remarkable success to classify the hundreds of hadronic particles that appeared in experiments of the 1960's.

The need for a fourth quark was later suggested to explain a phenomenon observed in those subnuclear interactions responsible for the beta decay of nuclei. No candidate for such a particle was observed until November 1974, so the theory was not taken seriously until then. Because of its striking properties, the fourth quark is said to be "charmed"; its existence implies a whole new family of hadronic particles.

"Charm" is an attribute or behavioral characteristic which, like electric charge, is additive. Nature produces a charmed system by providing pairs of charmed quarks, one positive the other negative. Charm appears in integral units (0, 1, 2, etc.) both positive and negative. Once charm exists it is almost indestructible. Conversely it is almost impossible to change a system with no charm into a system with charm.

Although difficult to destroy, charm is not completely indestructible. Over very long times it is possible for charm to disappear owing to the effect of weak interactions, weak because they take so long to act. As a result, charmed particles are long lived; longevity is their distinctive characteristic over other hadrons.

The discovery of the charmed baryon by physicists from Columbia University, Fermilab, the University of Illinois, and the University of Hawaii is believed to confirm the presence of "charm" in nature. The

baryon mass of 2.26 billion electron volts, its long lifetime before disintegration, and its final products of decay exactly fit expectations based on the four-quark picture.

The group leader of the research team that found the new particle was Wonyong Lee of Columbia University. The effort at Columbia University was supported through a grant from the National Science Foundation, and the experiment was performed at the Fermi National Accelerator Laboratory.

In the experiment, a beam of high energy gamma rays was directed at a beryllium target, producing many particles. Some of those emerging from the target were baryons that exhibited the characteristic longevity of a charmed particle. The baryon's disintegration products were an anti-lambda baryon and two pi mesons, none of which carried the charm attribute. The charm characteristic disappeared during the disintegration. Through the weak interaction it was converted into another attribute known to physicists as "strangeness." The strangeness is identified through the presence of the anti-lambda baryon. A short time later, billionths of a second, even the strangeness disappeared, when the anti-lambda baryon decayed into an anti-proton baryon and a pi meson. In total there were five observed particles which gave the event its unique signature. The charmed events are rare; 50 such events were found among 15 million high energy gamma ray interactions in the target.

The Columbia-Fermilab-Illinois-Hawaii team, long interested in charm, intensified its search for the characteristic following the discoveries in November 1974 of the J or Psi particle—found simultaneously by others at Brookhaven National Laboratory and Stanford Linear Accelerator Center. (Those exciting discoveries resulted in Nobel prizes in 1976 for leaders of the two groups.) This particle, similarly detected through its decay products, remained intact too long before disintegrating to be described by the three-quark picture. The J/Psi was, therefore, presumed to be made of a quark carrying a unit of positive charm and an anti-quark carrying a unit of negative charm.

In the combination of the J/Psi particle, the net charm carried is zero; the charm of the quark is annulled by the negative charm of the anti-quark. Although the J/Psi and similar states discovered shortly thereafter supplied strong supporting evidence, to confirm the reality of charm it was necessary to find particles in which a charmed quark combined with one or more of the three other types of quarks—those which do not carry charm and which impose no neutralizing effect.

Charm, however, remained elusive. A single event believed to carry charm had been found among neutrino interactions in a bubble chamber at Brookhaven National Laboratory. Not much can be learned, however, from a single event. Other searches over the past two years were futile. It was not until the finding reported by the Columbia-Fermilab-Illinois-Hawaii group that this latest link between observation and prediction had been made.

In summary, the basic combination of quarks forming charmed baryons has been found. Physicists are confident that in addition to these charmed particles, a rich spectrum of others, many of which will have higher masses, await discovery.

Possible Existence of Superheavy Nuclei

One of the models that physicists use to envision the nuclei of atoms pictures the components, protons and neutrons, as arranged in orbits or *shells* so that the individual nucleons can move without bumping into each other. Each shell can accommodate a certain number of particles; the lower shells generally hold fewer nucleons than higher shells. A nucleus which has just enough protons or neutrons or both to fill its outermost shell is especially stable, i.e., more likely to have formed in the past and less likely to disintegrate once formed. The numbers 2, 8, 20, 28, 50, 82, and 126 were designated "magic numbers" because nuclei with these numbers of *neutrons* were known to be more stable, even though stable elements in the higher *proton* numbers had not been observed.

The heaviest commonly occurring element is plutonium, which has 94 protons (Z=94). Nuclei with up to 103 protons have been found in nature or created artificially in particle accelerators. Nuclei having in the range of 114 to 130 protons were predicted to exist; the "magic number" 126 protons should produce the "Island of Stability": a family of relatively stable nuclei.

Although evidence for these *superheavy nuclei* has been sought in fusion experiments and in meteorites, results of a new experiment announced in June 1976 give evidence that some of these nuclei may occur naturally and be more stable than expected. The experiment is a collaboration between a geochemist, R.V. Gentry, Oak Ridge National Laboratory, and six nuclear physicists—T.A. Cahill and R.G. Flocchini of the University of California, Davis; and N.R. Fletcher, H.C. Kaufman, L.R. Medsker, and J.W. Nelson of Florida State University.

Heavy elements contained in microscopic crystal inclusions in transparent materials such as mica can reveal themselves by the presence of halos surrounding the inclusion. The halos result from the radiation damage of alpha particles spontaneously emitted by "actinides"—certain heavy radioactive elements. The size of the halo depends on the energy of the alpha particles. In some cases, so-called giant halos, 50 to 100 microns in diameter, surround in-

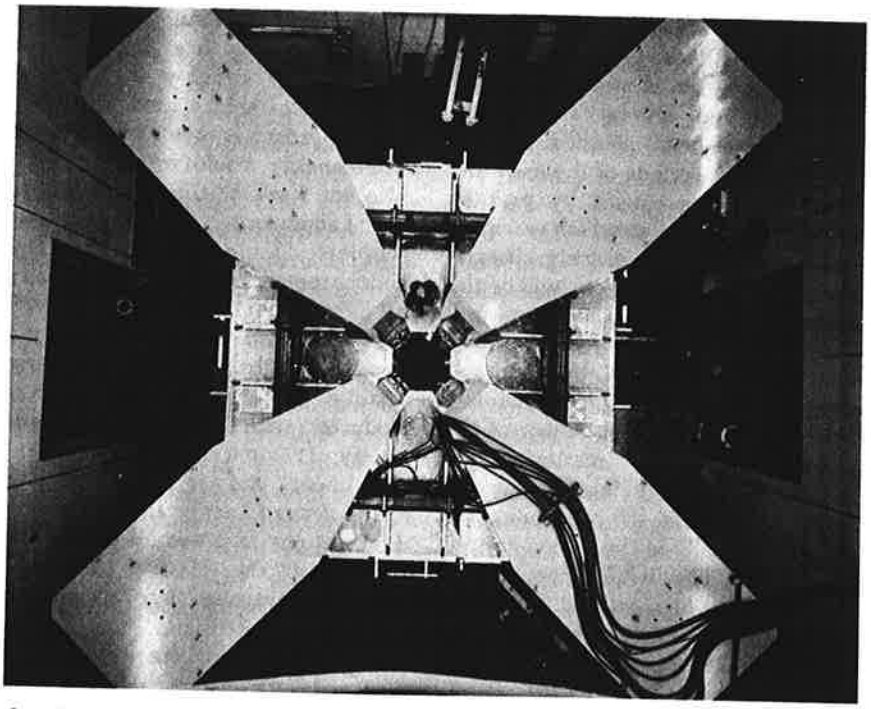
clusions. These would require alpha particle decay energies substantially larger than those of known actinide elements such as thorium or actinium. In this experiment, monazite inclusions in biotite mica were bombarded by energetic protons. Inclusions surrounded by normal and giant halos were irradiated by 4.7 and 5.7 million electron volt (MeV) protons from the Florida State tandem Van de Graaff accelerator. The experiment was designed to detect X-rays that would be produced if an incoming proton knocked an electron out of the second electronic level of a superheavy atom and an electron from the third level subsequently cascaded down to fill the hole. The energy of the X-rays produced in the cascade depends on the charge of the nucleus of the atom.

From detailed analysis of the energies and relative intensities of the resulting X-rays, as well as the absence of good alternative explanations, the experimenters concluded the X-rays may have been produced by elements with 116 and 126 protons. The evidence for element 124 is less strong.

Experiments with improved sensitivity are under way at Florida State, and they should help to confirm or deny the existence of superheavy elements. A confirmation will be particularly interesting because it would imply that the superheavy elements have lifetimes against decay that are considerably longer than have been predicted.

Indiana University Cyclotron Facility

On April 23-24, 1976, a new, NSF-supported national facility for nuclear science research, the Indiana University Cyclotron Facility (IUCF), was dedicated. Construction began in 1968 on this unique, three-stage nuclear accelerator. The first external beam was obtained in September 1975, and the first experimental data were taken in October 1975. The cyclotron was operated at 150 MeV during most of 1976; the full energy of 200 MeV was scheduled to be achieved by the end of the year.



A national facility. The new Indiana University Cyclotron will be used to study fine details of the structure and forces of atomic nuclei. Its four separated magnetic sectors (the man standing near the center shows their size) simplify the highly efficient particle accelerator, ease maintenance, and permit operation with low electrical power consumption.

The central apparatus of the IUCF is a three-stage accelerator consisting of a Cockcroft-Walton preinjector and two cyclotrons, which are identical except for scale—the main cyclotron is four times larger than the injector cyclotron.

Each successive stage accelerates positively charged particles to higher energy until they are directed at a target by the main cyclotron. The expected energies of protons as they are released from each stage are: 0.6 MeV from the preinjector, 15 MeV from the injector cyclotron, and 200 MeV from the main cyclotron. By changing the magnetic fields and the accelerating voltages other energies can easily be obtained. Other particles such as deuterons, alpha particles, and lithium nuclei can also be accelerated.

The main cyclotron operates, in principle, with 100 percent injection efficiency and 100 percent extraction efficiency, all the injected beam being transported to the target with an energy resolution of 0.04 percent or smaller. This permits very high quality experiments to be performed and means that very little residual radioactivity will be produced in the cyclotron so that servicing and improvements will be simplified.

The separated sector design of the cyclotron gives a variety of advantages—simplicity, accessibility of components, ability to operate the radiofrequency system at high voltages, and unusually low electrical power consumption.

The class of experiments to be

performed with the new machine will cover fine details of nuclear structure and nuclear forces. The contemplated research program is multifaceted and extensive, and several specific activities have been planned for the early running periods of the machine. Pion production caused by protons bombarding nuclei, in which reactions yield neutral and positively charged pions from several targets, will be the subject of both early experiments and theoretical work at IUCF. Elastic scattering from both protons and composite projectiles off nuclei will test various theoretical models of the scattering. Elastic scattering of deuterons, ^{3}He (helium), and ^{6}Li (lithium) will be of continuing interest, especially as the beam energies are raised. The IUCF spectrograph will be used for inelastic scattering studies, involving proton and deuteron excitation on a variety of nuclear targets.

The experimental program is approximately one-third in-house, one-third outside user, and one-third inside-outside collaborations. All experimental proposals are considered on an equal basis by a Program Advisory Committee, and a university-appointed committee advises on policy. Both these committees are appointed from the national science community. Also, an elected User Group Committee is very active in the operation of the facility.

Improved Resolution of Atomic and Molecular Structure

Essentially all atoms and molecules should exhibit interactions that have not been detected because of the limited energy resolution of electron beams available. Most of these interactions have not been adequately observed over their full energy range or width, or assigned accurate energies. Many other interactions have doubtless gone undetected for the same reason, while many known ones have undetected fine-structure. Conventional techniques for electron beam generation are limited to a resolution of roughly a 50 milli-electron volt (meV) spread. However, a new approach is now yielding much better energy resolution.

Recent work at the Joint Institute for Laboratory Astrophysics at Boulder, Colo., utilized the monochromaticity and high intensity of light from a laser to detach electrons from barium atoms and form an electron beam of uniform velocity. The photoelectrons are thus produced with a uniform kinetic energy (17 meV in the present experiment), and are then accelerated to the desired energy and focused on target atoms in a second beam. The energy of the electron beam is carefully controlled by varying the accelerating potential.

First results—for the scattering of monoenergetic electrons from argon atoms—are very encouraging. As the beam interacts with the argon atoms, some electrons are temporarily bound, forming an unstable, negatively charged atom, argon-minus (A^-). After an instant, the A^- disintegrates, scattering the electron in a direction different from its original path. Slight changes in electron energy greatly increase or decrease the probability of scattering. The energy range over which the scattering probability is high is called a resonance. The resonance studied is expected, from theoretical considerations, to have a natural energy spread of 3 to 5 meV; and its observation at about 6 meV is close enough to confirm the theory. Methods for further sharpening the instrumental resolution are being tested, and still narrower resonances are being observed.

This new technique opens up an entirely new level of detail of atomic and molecular structure to accurate observations and allows a number of important predictions of the theory of atomic structure to be checked.

Chemistry

Chemistry deals with the forces that bind atoms into molecules, the forces between molecules that account for the different forms of matter, and the way the forces can be altered for useful purposes. Chemical reactions are the transformations among atoms and molecules that bring about new arrangements of atoms in new molecules. Chemists synthesize new molecules, explore the ways in which chemical reactions occur, analyze the products of their labors, develop concepts that relate to structure and function, study the energetics of chemical and physical changes from the molecular to macroscopic levels, and ultimately try to relate these behaviors to the distributions of electrons in molecules.

Chemistry has changed remarkably in the past decade, propelled by a combination of fresh ideas from the scientific community, technological advances in computers (which have become an intrinsic part of chemical instrumentation), and Federal support for research. The environmental legislation of 1970 provided the driving force for a host of new inquiries into the nature of chemical reactions of critical importance to mankind. More recently the energy crisis has stimulated urgent inquiry into energy-related chemistry in such fields as synthesis, dynamics, thermodynamics, and chemical analysis, each of which is inescapably related to effective solutions of the energy problem. Each of these is a factor that has underscored the significance of NSF support of fundamental research in a wide variety of chemical dis-

ciplines. This support has contributed to recent revolutions in the way we think about many chemical interactions and processes.

Perhaps the next revolution in chemistry is already under way. Technological developments in lasers and, consequently, laser chemistry are beginning to provide startling advances in the understanding of chemical reactions on a time scale never before achievable. The laser is a superior radiation source that provides the chemist a tool for selectively breaking chemical bonds, for the selective excitation of vibrations that enhance chemical reactions, and for probing the ways in which energy is transferred in intramolecular and intermolecular processes.

Basic chemical research also underpins a crucial component of our national economy. Chemists educated in our network of research-based universities provide the intellectual sustenance on which the chemical industry relies for staffing its research laboratories, its production facilities, its technical service operations, and its management at all levels.

Molecular Details of Heterogeneous Catalysis

The term catalysis comes from the Greek *kata*—down, and *lyein*—loosen. Jons Jacob Berzelius used this term in 1835 to correlate a number of observations made by other chemists in the 18th and early 19th centuries. Chemical agents found to promote reactions were called catalysts, and Berzelius postulated a special force to account for these accelerations. Today catalysts play a crucial economic role in the chemical industry, and perhaps of even greater importance is the fact that nearly all of the processes of life involve catalysts of some sort.

A heterogeneous catalyst is ordinarily a solid substance; the catalytic function occurs at its surface. It has been estimated that the value of goods produced annually in this country which involve at least one heterogeneous catalytic conversion step in their manufacture exceeds $100 billion. These uses include the fine chemical and pharmaceutical industries, the oil and petrochemical industries, and the conversion of noxious pollutants prior to their discharge into our environment. Despite the importance of heterogeneous catalysts and their ubiquitous use, the molecular details by which catalysts function are largely unknown. If these details were understood, then catalysts could be tailored for specific use. This could improve their efficiency and return vast savings in precious raw materials and energy.

An enduring controversy among chemists is whether the geometry or the electronic structure of a surface determines the catalytic efficiency. Both are, in fact, important, and both must be understood if the mechanisms of elementary catalytic reactions are to be comprehended. It is essential to obtain both a compositional analysis and a measurement of the vibrational structure of the catalyst surface during the course of the chemical reaction. The reaction rate may be related to the composition, whereas the vibrational structure is important in characterizing molecular reaction intermediates and in formulating the reaction mechanism (that is, the pathway) by which reactants are converted to reaction products. Thus, a serious theoretical effort to describe the mechanisms of catalysis must be coupled to the careful measurement of surface geometry, electronic structure, compositional analysis, and vibrational structure. Finally, a measurement of catalytic reaction rates is also mandatory.

The experimental research by W. Henry Weinberg at the California Institute of Technology has as a goal the understanding of all these in molecular detail. To insure that the work is performed on well characterized systems, the catalysts are prepared in an extremely antiseptic environment, and Weinberg must perform the experiments at a pressure comparable to that found in interplanetary space. The experimental techniques used are complicated, but the insight gained is a major step toward understanding the heterogeneous catalytic process.

Weinberg is investigating the methanation reaction in which hydrogen and carbon monoxide are combined to form methane (a clean fuel), plus the hydrogenation of polynuclear aromatic molecules. These latter complex molecules are found in coal tars and are also products of the liquefaction of coal; to be useful, however, they must be modified further by chemical cracking. This is accomplished by adding hydrogen to them through the hydrogenation reaction. Weinberg's research also bears on pollution control since he studies the oxidation of carbon monoxide and the simultaneous reduction of nitric oxide. This catalytic reaction, where carbon monoxide and nitric oxide are converted to the harmless reaction products carbon dioxide and nitrogen, occurs readily in the presence of metals in the expensive platinum group, such as platinum, palladium, rhodium, and iridium. By understanding the way in which the catalysts function, it may be possible to design cheaper substitutes.

Fixing the Molecules of Life: Bioinorganic Catalysis

Nitrogen, water, carbon dioxide, and oxygen are basic to the Earth's biological cycle. These molecules might even be called the molecules of life, because they are essential in two of the most important biological processes: photosynthesis and nitrogen fixation. The reactions between these molecules in plants yield the amino acids and carbohydrates that are the essence of

the food we eat. And the energy from photosynthesis is released when carbohydrates react with oxygen, as in oxidation metabolism, another fundamental life sustaining process.

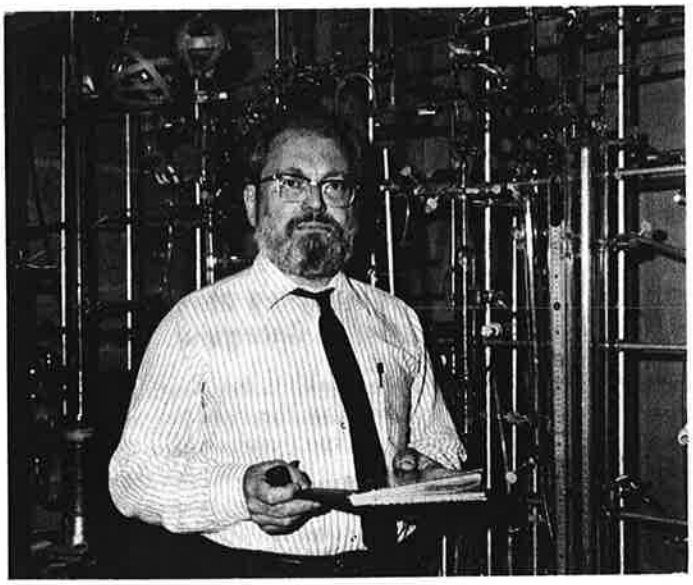
In nature, photosynthesis provides for the direct use and storage of solar energy. However, biological photosynthesis, or fixation of carbon dioxide and splitting of water, is an extremely complex series of chemical reactions that are not completely understood. One of the challenging questions facing scientists today is whether such a reaction, or a similar one, can be mimicked in a less complicated way in the laboratory. These mimicked reactions are simpler than nature's, but they may resemble the corresponding biological process at least in some fundamental fashion.

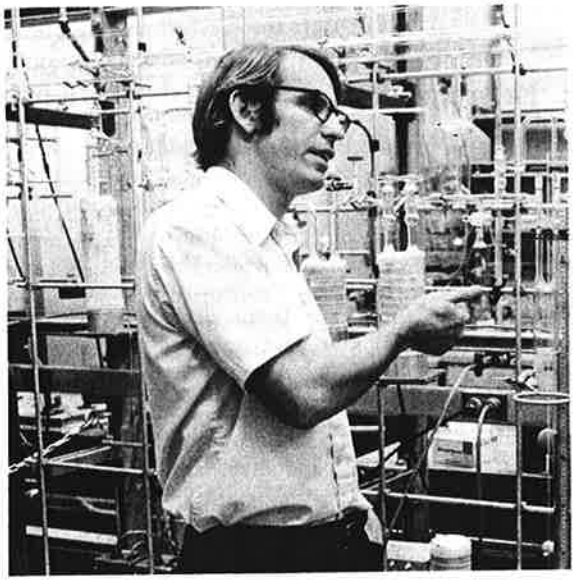
Lauri Vaska at Clarkson College of Technology has discovered and determined the reaction by which certain simple compounds of iridium and rhodium (two metals of the platinum family) fix carbon dioxide under ambient conditions. The reactions occur in solution as well as between the solid metal compounds and gaseous CO_2. The products contain "fixed carbon dioxide," i.e., its structure and the carbon-oxygen bond properties are different from those of the free molecule. Based on spectral and chemical properties, the carbon dioxide in the product is considered to be bonded to the metal through carbon.

Although the reactions of metal complexes with numerous small molecules (such as hydrogen, oxygen, and nitrogen) have been studied extensively during the past decade, studies involving carbon dioxide are of relatively recent origin. The importance of Vaska's discoveries lies in the fact that these reactions are reversible. Gaseous carbon dioxide is recovered when the system is evacuated. Iridium and rhodium complexes that react with Co_2 might act as catalysts for the conversion of carbon dioxide to a carbohydrate in the presence of a hydrogen source (e.g. water) and radiant energy. Experiments are under way to test this hypothesis.

Another achievement of important chemical consequence has been the isolation and structural characterization of a crucial intermediate product in a synthetic nitrogen-fixing system. This was done in the laboratory of John E. Bercaw at the California Institute of Technology. The development of synthetic nitrogen-fixing systems could lead to more economical production of fertilizers and other nitrogen-based chemicals, which subsequently would have an impact on worldwide food and energy issues.

Bercaw has developed synthetic routes leading to two related compounds containing either titanium or zirconium. These two compounds, permethyltitanocene, $(C_5Me_5)_2Ti$, and permethylzirconocene, $(C_5Me_5)_2Zr$, are extremely reactive and readily absorb molecular nitrogen (N_2) when exposed to a nitrogen atmosphere. Subsequent treatment of the resulting "dinitrogen complexes" with hydrogen chloride cleanly reduces a nitrogen molecule to hydrazine (N_2H_4).





Chemical fixes. Lauri Vaska at Clarkson College (left) and John Bercaw at Caltech (right), in separate research projects, have made progress in trying to mimic important biological processes in their laboratories. Knowledge gained from both Vaska's work on photosynthesis-like reactions to fix carbon dioxide and Bercaw's research on a synthetic nitrogen-fixing system may someday prove important to problems of food and energy supplies.

While a number of other transition metal-dinitrogen complexes have been synthesized since their discovery in 1965, it has not been possible to reduce their bound molecular nitrogen chemically. The unique characteristics responsible for chemical activation of N_2 when bound to permethylzirconocene and permethyltitanocene are, therefore, of considerable interest.

Infrared-Laser Photochemistry

One of the oldest methods of performing a chemical reaction is to simply heat a compound until one or more chemical bonds break. Reactions of this type, known as thermal decompositions, are very useful in the petroleum industry, in polymer chemistry and, indeed, in most areas of chemistry concerned with transformations of matter into other forms. One drawback of the conventional heating of compounds is that it energizes all chemical bonds to about the same extent. Consequently, reactions are difficult to control and require large inputs of energy. In addition, the striking feature of the process is that the decompositions tend to occur at only the weakest bonds in the molecule. This means that if one desires to break a strong bond in a molecule but leave a weaker bond intact, an indirect method is needed, usually one involving more than one chemical transformation.

In recent years, chemists have started using lasers to provide energy for driving chemical reactions. One of the most remarkable applications of lasers for this purpose involves the use of high power (megawatt) carbon dioxide lasers. These lasers emit a large flux of coherent radiation in the infrared region of the electromagnetic spectrum. This radiation can be used to supply energy to chemical bonds. However, unlike thermal heating, the carbon dioxide laser can be tuned to a precise wavelength that corresponds to a vibration of a specific bond in a molecule. In this way, energy may be put into a specific chemical bond without energizing any other bonds.

Ernest Grunwald of Brandeis University has begun a study of the irradiation of selected molecules using the carbon dioxide laser. His early results show that this method has the potential of becoming extremely useful in allowing selective decomposition of certain bonds in a molecule, while keeping others intact. He finds that when compounds such as fluorocarbons are irradiated with pulses of infrared radiation from a megawatt carbon dioxide laser tuned to a specific vibration of the target molecule, the compounds decompose via clearly defined pathways.

Another remarkable aspect of the laser irradiation is that several quanta of energy are absorbed by specific chemical bonds. This is a direct result of the special properties of laser radiation. The radiation is both very intense and coherent and can be tuned to the precise frequency of a strong absorption in a molecule. This facilitates the absorption of many quanta of energy. Moreover, all the absorbed energy becomes "locked" into only the one molecular vibration that is absorbing the laser radiation. The net result is that this one vibration is excited as if the particular bond were heated to a very high temperature. The bond rupture occurs even though the total energy of the radiation absorbed by the molecule is less than the amount of energy needed to decompose the substance thermally.

When a molecule is heated to a high temperature, only a small portion of the applied heat is used in the decomposition process. The applied heat is distributed among all the vibrations in the molecule, and individual molecules collide and transfer parts of the heat energy to other molecules and to the walls of the container. In the laser-induced reaction, on the other hand, *most* of the absorbed energy goes into energizing a particular chemical bond and thus is available to initiate the decomposition reaction. As a result, the infrared laser induced process is very efficient.

Infrared laser photochemistry is in its infancy. The early results, however, indicate that it could be revolutionary for synthetic chemistry. In principle, it should be possible to apply infrared photochemistry to synthesis of otherwise inaccessible molecules and also to activate molecules using small fractions of the energy that has heretofore been needed. Further new developments are expected in the near future from several laboratories. The current major obstacle is the lack of tunable, high power infrared lasers, other than the carbon dioxide laser. Rapid development of that field, however, is expected to remove that limitation.

Chemical Instrumentation

Practically all current scientific endeavors, particularly modern chemistry, are based on measurements and on modern instrumentation. Instruments such as infrared and nuclear magnetic resonance spectrometers, mass spectrometers, chromatographs, as well as a variety of other types, are indispensable to chemical research. In addition, the revolution in modern electronics has dramatically improved the capabilities of these standard instruments and made available two powerful new tools: the microcomputer and the high power laser. The Foundation's chemical research instrumentation program has provided the major share of Federal funding for supporting major instrumentation in chemistry departments and for the development of new instrumentation needed in chemistry.

Development in nuclear magnetic resonance spectrometers over the past 5 years provides an excellent

example of the major improvements made in modern instruments and of the new areas of chemical research that develop as a result of these advances. Magnetic resonance spectroscopy of protons provides chemists with two basic pieces of information: (1) the chemical environment of hydrogen atoms present (e.g. CH_3, H-C=C, OH, etc.) and (2) the quantity of each proton species present. Although conventional proton nuclear magnetic resonance is one of the most powerful tools at the chemist's disposal, it has a number of drawbacks:

- It is not very sensitive; 100 milligrams or more per sample are needed.
- In complex molecules, interpretation of the proton spectra can be difficult and sometimes ambiguous.
- Only liquid samples can be studied.
- Information about chemical or molecular dynamics is very limited.
- The instruments are difficult to operate and maintain.

With the advent of fast, reliable, low cost minicomputers and microcomputers, Fourier-transform spectrometry has replaced the older methods. The fast Fourier-transform technology has greatly enhanced the chemical utility of nuclear magnetic resonance spectroscopy of protons and carbon-13.

Some of the advances include:

- Obtaining spectra from 10-microgram proton samples is now routine, and 500-nanogram and smaller samples can be measured provided that the sample is pure.
- Natural abundance carbon-13 spectra are often simpler to interpret than proton spectra and provide a wealth of new information.
- In many cases high resolution nuclear magnetic resonance spectra can now be obtained on solids.
- A wide range of new information concerning chemical and molecular dynamics is now available.
- The new instruments are extremely reliable and easy to operate.

This instrumentation development has revolutionized organic chemistry, clinical chemistry, natural products chemistry, and many other areas.

An exciting new development is the work of John Waugh and his research group at the Massachusetts Institute of Technology. By using the full power of the pulsed Fourier-transform nuclear magnetic resonance method they have been able to obtain resolution carbon-13 nuclear magnetic resonance spectra of *solid* samples. One especially interesting direct consequence of Waugh's research is the application of this method by E.O. Stejskal and Jacob Schaefer of the Monsanto Company to the *in-situ* analysis of various seeds, such as soybeans and wheat, for the composition of the various oils, starches, and proteins in the seeds. Since the nuclear magnetic resonance method is totally non-destructive, the seed can be planted after analysis. This technique can save years in the amount of time required to develop new plant hybrids whose constituents are tailored to specific end uses. Another variation of this new method, using double Fourier-transform techniques, has enabled Waugh to measure, in favorable cases, the exact geometrical position of the hydrogen atoms in crystalline samples to a precision of 0.01 atomic units. Such precision is competitive with the widely used method of X-ray diffraction; the new method, however, is at its best in locating hydrogen atoms that are not normally observable via X-ray techniques.

Mathematical and Computer Sciences

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

In terms of dollar obligations, core mathematics represents about 75 percent of the NSF mathematical sciences program, and applied mathematics about 25 percent. In the instance of core mathematics, NSF supports most of the national effort. While it is difficult to obtain accurate

estimates of the total support by NSF relative to that of other agencies because of administrative and definitional differences, available data indicate that NSF accounts for about 60 percent of the total Federal support of the mathematical sciences, and about 90 percent of the support of core mathematics.

The health of mathematics in the United States is good. Research in this country continues on at least as high a level in quality and probably higher in quantity than at any time in our history. Major trends in research that have gradually emerged in recent time and continue to manifest themselves are: (1) the confluence of older fields to produce new and dynamic fields of research; (2) the solution of important problems of ancient vintage; and (3) the increasing importance of algebraic methods in the applications of mathematics.

Unlike the mathematical sciences, which have a long and rich tradition, computer science is barely 10 years old. Owing to its rapid development, trends are more easily discerned than in a more established discipline. Perhaps the most striking change has been the 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 with the role of mathematics in science. Each scientific discipline devises its own mathematical methodology for solving the problems of concern to its own area. In doing so it draws from mathematics' incredibly varied and centuries-old framework. These mathematical constructs often arose from practical needs of the time that spawned them; often they were products of a quest for mathematical elegance 8nd 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 that same kind of role. Not long ago a scientist who was adept at using a computer in the solution of a particular class of problems, and who made this his principal activity, would be called a computer scientist. Today, this is becoming less true; research is revealing structural similarities among some apparently very different problems when they are viewed from the perspective of computing, and 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 sciences.

The Invariant Subspace Problem

Hilbert spaces are infinite-dimensional generalizations of ordinary, finite, Euclidean n-spaces. They play a pervasive role in many branches of both pure and applied mathematics, from representations of groups to quantum mechanics to differential equations. As infinite-dimensional analogues, they carry both an algebraic vector structure, which permits the useful representation of many problems, and related geometry or topology, which permits mathematicians to bring their intuitions to bear. One of the most intensively studied objects in all of mathematics is that composed of all mappings of a Hilbert space that preserve important algebraic and geometric properties. These mappings are called the bounded linear operators on the Hilbert space. Some of them carry a portion—a subspace—of the Hilbert space back into itself. Such a mapping is termed "invariant." An important problem in Hilbert space theory, the Invariant Subspace Problem, asks whether every bounded linear operator has an invariant subspace (other than the zero vector and the entire space). Much work has been done on this problem, the resolution of which will allow greater understanding of the structure of bounded linear operators as well as of the spaces themselves.

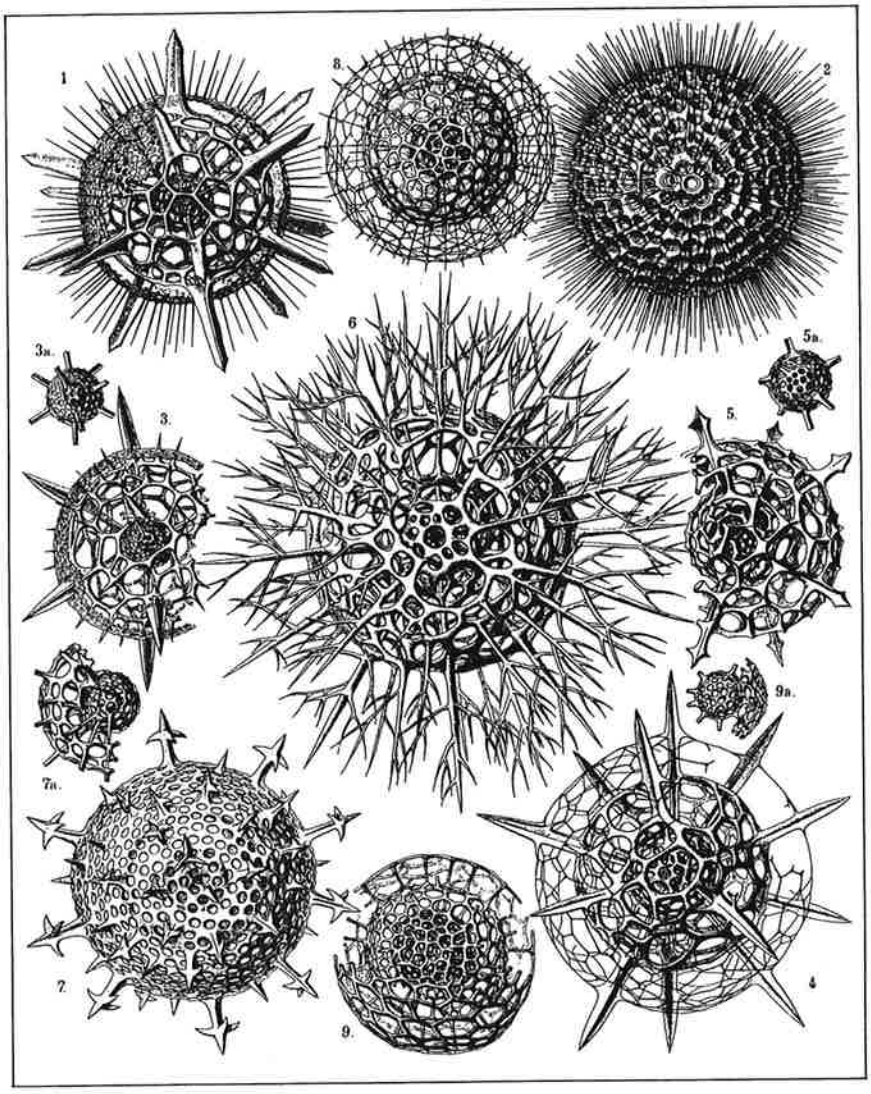
Important progress toward answering this question was made recently in both the positive and negative directions. A Russian, V.I. Lomonosov, showed during 1975-76 that the answer is yes for a large class of bounded linear operators. An equally important negative partial result was obtained last year by Per Enflo, of Stanford University, who produced a Banach space (a further generalization of a Hilbert space with a more complicated geometry) and an operator on that space such that the *only* invariant subspaces of the operator are the zero vector and the entire space.

Thus areas of uncertainty have been narrowed and interest in the problem has been heightened, so that the current high interest in the Invariant Subspace Problem seems certain to be intensified.

Recent Research on Geometry: Plateau's Problem

The elusive principles that govern the shapes assumed by bubbles and soap films have interested scientists and mathematicians for at least a century. Such a quest is not idle. Mathematicians pursue it because the principles involved have relevance to important studies of surfaces in geometry, and these, in turn, have relevance to minimal energy principles in physics and engineering.

Investigation of the number of different forms taken by bubbles and films suggests several possible principles: (1) A compound bubble or film stretched on a wire frame consists of flat or smoothly curved surfaces smoothly joined together. (2) There are only two ways in which the surfaces meet: Three surfaces can meet along a smooth curve, or six surfaces meeting along four curves can come together at a vertex. (3)



Mathematics meets biology. Skeletal remains of microscopic marine organisms called *Radiolaria* show the curves and angles formed by the bubbly froth of cells that surrounds the organisms' protoplasm when alive. The skeletons, all that survive when the animal dies, apparently form from the material deposited out of the cells at the film margins. (From Ernest Haeckel, *Report on The Radiolaria Collected by H.M.S. Challenger During The Years 1873-1886.)*

The junctions between curves always appear to meet at equal angles.

The Belgian physicist Joseph A. F. Plateau, who conducted his research more than a century ago, recorded these simple general rules. His name has been given to the wide range of problems stemming from these and related phenomena.

Recently, Frederick J. Almgren, Jr., of Princeton University, and Jean E. Taylor, of Rutgers, The State University, have been able to construct a mathematical model to show that the three basic rules governing the geometry of soap bubbles and soap films are a mathematical consequence of a simple area-minimizing principle. Their proof reveals the true geometric underpinning of Plateau's rules, and goes beyond, since the geometry of bubbles and films is not fully determined by Plateau's three rules. For example, the mean curvature of each separate piece of surface must be constant. This additional condition, and all other such conditions, appear to be satisified by the Almgren-Taylor model.

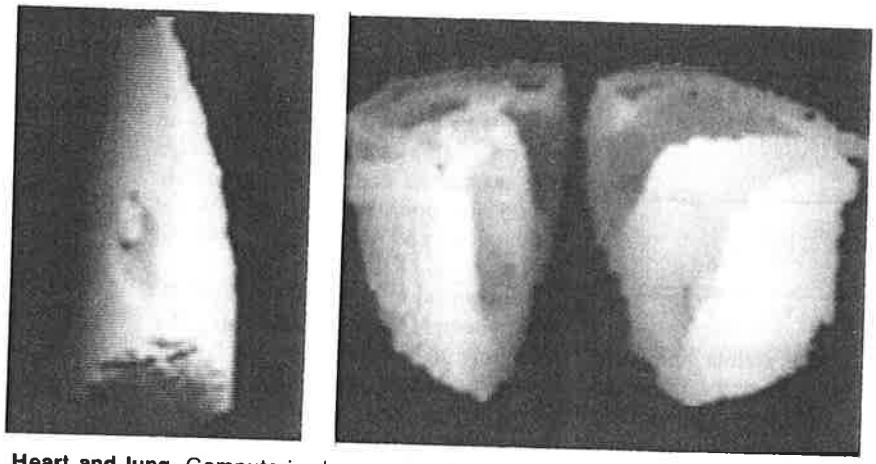
Models of this type can handle, with some modification, a number of variant problems. They can account for the shape of a liquid in a container of any form when capillary effects are present, and their additional application to changes in shape over time impinges upon an area of active mathematical research with many potential applications.

Pattern Recognition

The use of the computer to "look" at objects and describe what it "sees" sufficiently well so that either humans can make necessary decisions or other computer programs can make proper responses continues to be a forefront research area; it has also become an important part of many computer applications. This category of computer research is often termed pattern recognition or image processing.

One example of a project in this area which combines forefront research with an important application is an effort funded jointly by NSF and NIH's National Heart and Lung Institute. This project is attempting to develop three-dimensional reconstructions of rapidly moving organs such as the heart, and of large moving organs such as the lungs.

Computer processing of images provided by X-rays or ultrasound is already in widespread use for brain scanning and other medical pattern recognition problems where the parts of the body are stationary. But the analysis and representation of motion



Heart and lung. Computerized reconstructions in three dimensions of the beating heart (left) and lung (right, with an indentation showing the location of the heart) of intact animals are made possible by advanced mathematics and developing tomographic equipment. This technique promises to become a powerful new medical diagnostic tool. (Photos by Gabor Herman/SUNY-Buffalo.)

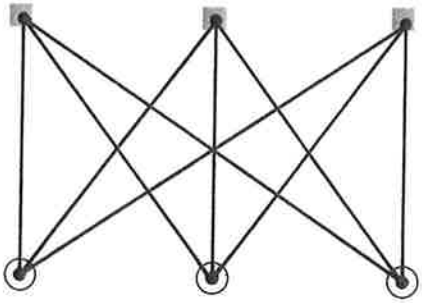
pose problems for which more efficient computer procedures (algorithms), more effective computer configurations, and more efficient mathematical processes are necessary. Thus, the research thrust focuses upon those areas.

The research so far—by Gabor T. Herman of the State University of New York at Buffalo, working with physiologists at the Mayo Clinic—has succeeded in X-raying the moving heart and lungs of experimental animals. The experiments, however, involve imposing constraints upon the subject that would be unacceptable in a clinical situation. Both the computer algorithms and the X-ray equipment are being modified, however, to bring what promises to be a powerful tool of medical diagnosis closer to fruition.

Graph Problems

Graphs can be used to describe the underlying structure of many problems that are solved on digital computers. These include, for example, process scheduling, minimization of circuit components, or traffic flow problems, as well as the operation of computer programs themselves. Because of the widespread occurrence of these kinds of problems, the procedures for solving them are attracting a good deal of research attention.

One example, representative of a broad class of graph problems, is the effort to determine whether a given graph, which may have been initially designed in three dimensions—in a prototype electronic circuit, for example—can be laid out on a plane without crossing wires. This is important to the design of circuit boards or integrated electronic circuits; the manufacturing process requires planarity, and crossed wires would lead to short circuits.



Non-planar. It is impossible to connect the three houses (squares) to the three utilities (circles) without at least one crossing, so the resulting graph must be three-dimensional. Knowing if a three-dimensional design can be represented on a two-dimensional graph is important in many applications, such as the layout of electronic circuit boards. As a result of recent research, such problems are now solvable with a greatly reduced number of steps.

Until recently the known algorithms required n^3 steps to solve this problem, where n is the number of vertices (i.e., terminals) in the graph. For a circuit with 100 connection points, about 1,000,000 operations were required. Now Robert Tarjan of Stanford University and John Hopcroft of Cornell University have discovered an algorithm that requires a number of steps only proportional to the number of vertices, i.e., approximately 100 for the example above.

This reduction was achieved by applying modern computer science techniques to mathematical results going back almost 250 years: the formula developed in 1736 by Swiss mathematician Leonhard Euler. From the Euler formula, one can deduce that, if a graph is planar, then there are no more than 3n-3 edges in the graph. Since this implies that the number of edges is linear in relation to the number of vertices, they sought an algorithm that is also linear.

The resulting algorithm employed three computer science techniques in an optimal way: The graph was broken down into smaller subgraphs, and it was proven that, if the subgraphs were planar, they could be recombined in such a manner as to embed the original graph in a plane; this built on previous results by L. Auslander and S.V. Parter (1961), who themselves had an n^3 algorithm. Then Tarjan and Hopcroft insured that the various edges were considered in an optimal order, so that once a set of edges had been considered, it would not have to be

reevaluated. And finally, they applied data structures of sufficient efficiency to insure that the data were accessed in the proper order. The result: a linear algorithm for the determination of the planarity of a multidimensional graph, in a manageable number of steps.

Engineering

American engineering schools can be proud of their success in educating world leaders in science-based innovative technology. To a large extent the schools' ability to do this in the future depends on continuing involvement of faculty and graduate students in research that provides new design principles, replaces empiricism by understanding, leads to fundamentally new approaches in device or process design, or shows how relatively new science can be applied to the solution of important problems in energy conversion, resource management, production, or other areas of man-environment interactions. Support for such research in universities is provided by NSF's engineering program.

NSF is the only principal source of funds for long-range engineering research, although colleges do obtain support for work on more short-range problems from NSF's Research Applied to National Needs (RANN) programs and from some mission-oriented agencies. Often the early, "high risk" stages of research are supported by NSF's engineering programs; later, when useful applications become clearly apparent, mission agencies or industry take over sponsorship or provide supplementary, expanded support.

The major research areas funded in engineering are electrical sciences and analysis (including systems science), engineering chemistry and energetics, and engineering mechanics.

The research effort in electrical sciences has had major impact on the newly emerging field of optical communications, where visible light and infrared are used in place of radio frequencies to make possible vastly greater volume and speed of information transfer. Work on new device concepts for information processing and measurement has been fostered by new developments in the understanding of the superconducting state of matter and by continued exploration of the properties of semiconductor materials. Research in plasma dynamics has led to an understanding of some phenomena that will be important to the eventual harnessing of the thermonuclear reaction for energy conversion.

New ideas in image analysis and processing have found important applications in medicine (radiology) and agriculture (remote sensing of crop damage); mathematical systems theory is being developed for application to complex energy systems, large, interconnected computer networks, and, possibly, socio-economic systems.

Research in engineering chemistry and energetics has led to a better understanding of mechanisms such as catalysis and mass transfer, which are fundamental to many chemical processes. New methods for determining thermodynamic properties of complex mixtures have been devised which will be extremely useful, for example, in processing of natural gas and in coal conversion, and in many other applications.

New mathematical techniques have been developed for the prediction of heat transfer in complex configurations; these are likely to lead to more efficient combustion with fewer pollutants. Progress has also been made in characterizing mathematically the size and shape of particles—an essential step for improved design and automatic control of particulate processing operations in the mineral industries and in waste disposal systems.

Substantial new predictive capability has been achieved in describing the transport of particle-carrying liquids through porous structures—knowledge that will have a major impact on the design of wastewater treatment facilities. Improved understanding of porous structures will also be important in devising systems for secondary and tertiary oil recovery from partially exhausted oil wells.

Research in engineering mechanics is concerned with problems in fluid and solid mechanics which are of fundamental importance to engineering design and must be solved if larger, more complex structures—buildings, dams, pressure vessels—are to be built safely with minimum use of energy and materials. Concern extends also to water resources and environmental engineering, pollution control, geotechnical engineering (which depends upon an understanding of the properties of rock and soil), and to biomechanics involving the application of solid and fluid mechanics to problems in biology or medicine.

New and deeper understanding of important phenomena has been obtained and new mathematical, computational, and measurement techniques have been applied, for example, to turbulent mixing of fluids, propagation of stress waves in pressure containment vessels, sediment transport in rivers, and behavior of frozen soils.

More Precise Thermodynamic Data

High purity separation and precise blending are two crucial operations in

the utilization of natural gas and gasified coal, both as fuels and as base chemicals. In order to achieve these objectives with minimal energy consumption, accurate thermodynamic data such as vapor-liquid equilibrium (VLE), mixture density, excess volume, and interaction coefficients are indispensible. Some of these data have heretofore resulted from very tedious experimental procedures while others must be calculated or predicted indirectly from measurable quantities, thereby incurring unacceptable errors. Such difficulties can now be overcome by the novel use of the Burnett apparatus.

A typical Burnett run consists of filling a cell with a fluid, raising it to some elevated pressure, and then making a series of constant-temperature expansions into an evacuated second cell, with the pressure recorded after each expansion. The advantage of this basic Burnett procedure is that it requires pressure and temperature measurements only, thereby eliminating errors associated with sampling and mass volume determinations.

Under support from NSF, K.R. Hall and his coworkers at Texas A&M University have carefully constructed a helium gas-bath thermostat to maintain the temperature within the apparatus constant to within 0.001° K. Using a standard platinum resistance thermometer, temperature measurement can be made to within 0.01° K. They have also developed a unique technique for using a differential pressure transducer, greatly simplifying observations and achieving precisions of better than 0.005 percent of the pressure, which are an order of magnitude better than current manufacturer specifications for this measurement.

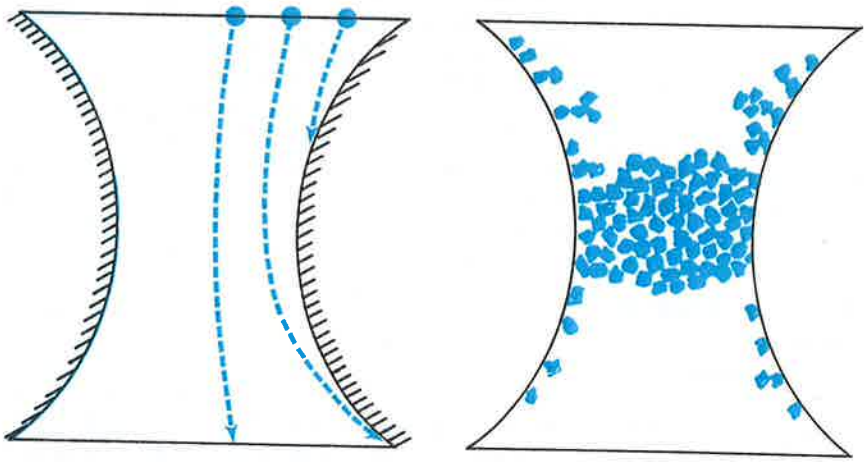
A novel coupling of the isochoric (constant-volume) method with the basic Burnett procedure has also contributed to this substantial increase in precision as well as further experimental efficiency. A less obvious but equally important advantage is that the volume distortion due to pressure can be observed experimentally relative to the base isotherm.

Hall and his coworkers have also devised a mixing experiment that will produce extremely precise compositions, excess volumes, and interaction coefficients, all within the framework of the coupled experiment. Most recently they have also conceived an experiment for vapor-liquid equilibrium studies by incorporating a magnetic densimeter into one of the Burnett cells. Basically the magnetic densimeter is simply a magnetic float that can be levitated in the fluid by a magnetic field. The current required to generate enough magnetic field to levitate the float is directly proportional to the density of the fluid containing it. Material balances allow the calculation of compositions from the liquid and vapor phase densities. Sampling and chromatographic analysis, which are the primary sources of errors in the VLE experiment, are thus eliminated. These researchers have successfully operated a prototype and are in the process of constructing a precise apparatus with which activity coefficients with 0.1 percent accuracies should be routinely possible.

This research was started with an NSF Research Initiation Grant to the University of Virginia, where Hall taught as an assistant professor. As the work proved to be successful and the results showed considerable promise for the energy industry, complementary support was provided from the American Gas Association.

Kinetics of Deep Bed Filtration

Transport processes within porous structures consititute a body of phenomena that are vitally important in many fields, including water and wastewater treatment, chemical reactor technology, hydrology, oil recovery, and biological systems. A continuing program of research in this area has already had a major impact on the field because it has succeeded in introducing a new and more realistic model of the porous structure. The research was started by an NSF grant to Chi Tien and Raffi M. Turian, of Syracuse Univer-



Filtration in deep porous beds. A new model to describe porous media—important in many purification and industrial chemical processes—predicts how particles are filtered from a fluid stream by collision with the channel wall (left). It also accounts for pore blockage by accumulation of relatively small particles (right).

sity, to carry out a theoretical and experimental study of filtration in deep porous beds, with assistance from then-graduate student A.C. Payatakes.

The accuracy of the porous media model they developed, which consisted of a statistically distributed array of periodically constricted tubes, was such as to be capable for the first time of quantitative prediction of the dynamic behavior of processes within porous structures. Their results represent the first rigorous and quantitative theory relating to filtration in deep beds. The porous media model predicts the rate of removal of particles from the fluid stream (rate of filtration) through calculation of particle trajectories. It also accounts for the tremendous increase of pressure drop and energy consumption caused by deposition of a relatively small amount of particles. The morphology of the particle deposits and the geometry of the porous media model show that entire channels can be closed to flow by lodging of a cluster of particles at a narrow passage.

This work has been followed by a resurgence of activity, as well as new contributions, in aerosol filtration, the morphology of particle deposits, heat and mass transfer in trickle beds, and adsorption and chemical reaction in packed bed systems. It led to the fact that Payatakes, now a professor at the University of Houston after a year in industry, became the first American to win the Suttle Award of the Filtration Society.

Dynamic Stress Analysis of Thick-Walled Pressure Vessels

An important pproblem that the nuclear power industry must deal with is determining the dynamic stresses and displacements in thick-walled spherical and cylindrical pressure vessels containing either air or liquid and subjected to impulsive and periodic impact loadings.

However, the standard analytic technique, using expensive finite difference or finite element computer codes, can handle only the simplest cases. In recent years a method that had been developed by geophysicists to analyze elastic waves in layered media bounded by plane surfaces was applied to this problem. At Cornell University, Y.H. Pao extended this Method of Generalized Rays to include curved surfaces in order to apply it to pressure vessels. Pao's method proved very powerful in handling the more complex cases, such as vessels with large thickness and off-axis loading. An important finding of this analysis is that large tensile radial stresses may develop in the vessel when subjected to dynamic loadings.

Under static internal pressure, the radial stress in a vessel is always compressive, with the peak magnitude being equal to the applied internal pressure. However, Pao's research demonstrated that under dynamic loading the radial stress can become tensile as a result of multiple reflections of the stress waves, and that under the most unfavorable conditions the tensile stress can be twice as large as the applied pressure. These results have not been reported before in the open literature, and the possibility of developing large tensile radial stresses is not included in the current design of concrete containment vessels for nuclear reactors. Since concrete is weak in resisting tensile stress, such a large tensile radial stress may generate cracks in the concrete or cause it to spall.

An unexpected result of this research relates to the current procedure for interpreting acoustic emission signals. Acoustic emission (AE) is a new technique being developed to detect the nature and location of cracks and materials defects from the acoustic signals (elastic waves) emitted by them. It is being applied in the nuclear power and other industries to detect the possible failure of pressure vessels. The current state of the art is to place a transducer on the structure and to count the number of events per unit time. This count is then used to identify empirically the nature of the source (defect) generating the acoustic emission. Pao has shown from his analysis that the count of events per unit time depends not only on the nature of the source, but also on many other factors such as distance between source and receiver, wall thickness, and the type of fluid being contained. Thus the existing AE technique of associating the count rate with the time history of the source is open to serious question.

In order to investigate this finding in more detail, Pao and W.H. Sachse have begun an experimental and theoretical study of pulse propagation in a plate. The properties of a pulse generated by a simulated source of defects are being examined to determine the relationship between the time history of the source function and the signal received at the transducer.

Novel Devices for Optical Communications

As the frequency of an information carrying wave increases, so does its potentially useful bandwidth: its ability to carry information. The use of microwaves has vastly increased the carrying capacity of communications channels. The next quantum jump is seen as being in the use of light as the carrying medium; with its enormously higher frequencies, it offers the promise of expanding useful bandwidths by hundreds to thousands of times.

This depends, of course, on the availability of the technology to transmit, receive, and convert the information carried in optical communications systems. Recent developments in the field have made

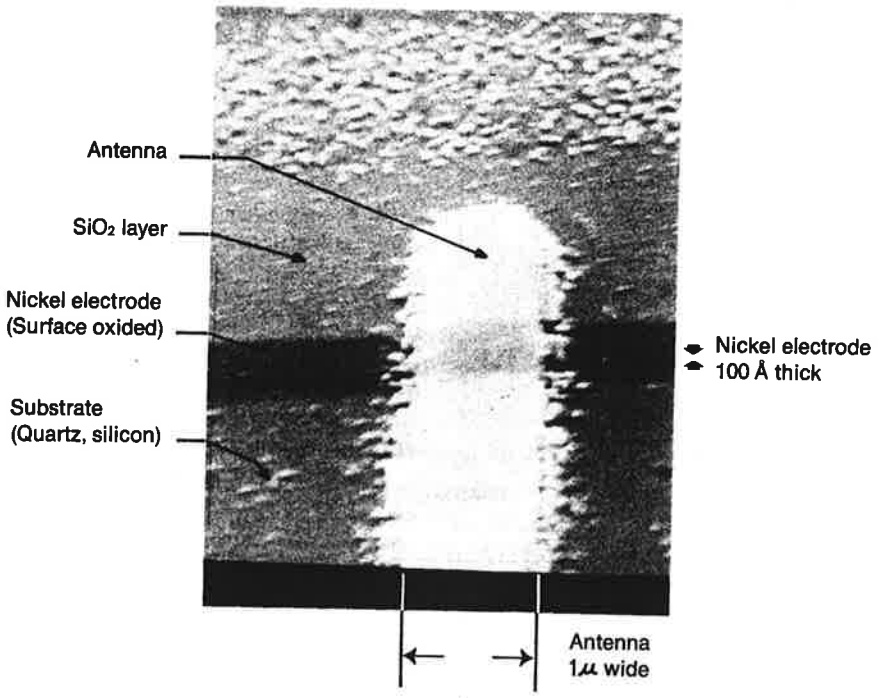
it clear that closely spaced metals have the inherent ability to provide the high capacity (wide bandwidth) needed for functions such as reception in light wave systems. It has been experimentally and theoretically determined that electronic currents at frequencies corresponding to infrared or light waves can flow between two such closely spaced metals. In addition, it has been observed that currents at two or more high frequencies can be mixed together to generate currents at new and very high frequencies. These results demonstrate significant characteristics that are required for subwavelength size infrared or optical frequency mixers, modulators, rectifiers, frequency converters, and many other communication elements which are commonplace at lower frequencies today and which are necessary for communication systems.

Why investigate metals for optical frequencies? First, the characteristic frequencies of metals are in the ultraviolet portion of the electromagnetic spectrum. The electronic cloud of a metal interacts strongly with optical radiation. Also, metals in close contact with one another can pass electrons between them within 10^{-16} seconds.

One of the processes through which a light wave interacts with closely spaced metals is called electron tunneling. This process depends upon the wave nature of electrons (quantum mechanical effect). Quantum-mechanically, the electron can travel through the barrier if the barrier is thin enough. In a typical tunneling process, a sharpened tungsten tip—as small as 300 Angstroms in radius—nearly touches a gold surface. A thin insulating layer separates the two metals to form the tunnel junction. If no voltage is applied to a tunneling junction, no net current of electrons flows from one metal electrode to another. When a voltage is applied across the junction, however, net current flows. The current-voltage characteristic exhibits nonlinear behavior that is associated with the tunneling current.

At the University of California, Berkeley, a number of key results have been obtained by T.K. Gustafson and his colleagues in this new field. The highlights of this research include the further experimental and theoretical verification of electronic models of tunneling and rectification processes at optical frequencies, the mixing of two optical frequencies, and the fabrication of thin film junction devices that have an extremely small area, similar to the point contact structure, and operate under conditions of high junction voltage and low junction current. It has also been shown theoretically that positive feedback in metal-metal tunneling junctions is possible. The last result implies that infrared and even optical oscillators and amplifiers are a possibility.

The study of the interaction between infrared or visible frequency radiation and tunneling currents is an important part of optical electronics. Further research in this area is likely to have a profound influence upon the future development of many electronic devices. In optical communication systems, the research may provide a unification of techniques used both in present electronic devices and in the emerging field of integrated optics, where ultrasmall components are required.



Optical hardware. The eventual development of the rich potential of optical communications depends on techniques to manipulate the optical signals in useful devices. Recent progress in the use of metal-to-metal junctions through which electrons tunnel shows promise. This nickel-gold junction diode, in which the gold antenna is only one-thousandth of a millimeter wide, responds to infrared or optical frequency voltages.

Materials Research

Materials impact to some degree virtually every aspect of modern civilization. They are of critical importance to manufacturing and service technologies, to national defense, and to the solution of complex energy and environmental problems. One of the principal objectives of NSF's materials research program is to improve man's understanding of the basic scientific principles and concepts that underlie the properties of materials. Pursuit of these objectives involves multiple science and engineering disciplines including solid state physics and chemistry, metallurgy, ceramics, and polymer science.

Although materials research advanced across a broad front during the past year, particularly noteworthy progress occurred in the areas of surface science, superconductivity, and in the preparation of materials possessing unusual properties. Sophisticated, new experimental techniques played key roles in many of these developments, and none more so than synchrotron radiation. In addition to its exceptional intensity, short pulse length, and spatial directionality, synchrotron radiation is nearly 100 percent plane-polarized. This last property has been used by N. Smith and M. Traum of Bell Labs and G. Lapeyre and his coworkers at Montana State to study the angular-dependent photoemission of electrons from the layer-compound tantalum sulfide. These observations, conducted at the synchrotron radiation facility at the University of Wisconsin, provide insights into the symmetry and energy-dependence of the local electronic states. Such information is critically important to catalysis research (the search for ways to speed up specific chemical reactions) in that it provides an understanding of the atomic nature of surfaces and how surface atoms are affected by adsorbed molecules.

In understanding how catalysts work, one must know the sequence of steps by which the initial reactants are converted to the desired products, i.e., the "reaction mechanism." At the California Institute of Technology, W.G. Goddard, III, and his collaborators have successfully used quantum theoretical methods to calculate the relative stabilities of surface species. These initial results, which will be carefully tested against additional experiments, permit them to identify highly unlikely reaction mechanisms and to propose more reasonable alternatives.

Metallurgists are also contributing to the advancement of catalysis research by studying particle agglomeration and sintering in catalysis support systems. Cooperative research efforts by J. Tien at Columbia University and N. Gjostein at Ford Scientific Laboratories have shown that decrease of catalytic surface area is the primary reason for the thermal degradation of supported catalysts.

A combined theoretical and experimental study at the University of California, San Diego, under the direction of H. Suhl and M. B. Maple, has demonstrated the effect of a ferromagnetic phase transition in nickel on the rate of surface oxidation. Similar effects have been observed near the ferroelectric transition temperature of potassium niobate and the structural transition temperature of cobalt. It is speculated that these fluctuations determine the rate of catalytic reactions, and if understood, could result in the development of more effective catalysts.

A number of interesting new materials have evolved from NSF programs during the past year. At the University of Chicago, J. Ito and his collaborators have succeeded for the first time in growing sizable, gem-quality, single crystals of several silicates by a high temperature solvent growth method. The availability of such specimens for chemical, structural, and physical property measurements has always been crucial to progress in materials research.

Scientists at the University of Pennsylvania are synthesizing selected intercalated graphite compounds for the purpose of understanding how their physical properties are related to crystallographic, chemical, and electronic structure factors. In one instance, graphite reacted with antimony pentafluoride yielded a material whose electrical conductivity was about 150 percent that of pure copper. In the long term, such fundamental studies could have great practical significance. Graphite is abundant, lighter than copper, and can be formed as exceedingly strong fibers.

Finally, efforts by R. W. Lenz and W. J. McKnight at the University of Massachusetts have resulted in unusual polymeric materials that function as either rigid plastics or flexible rubbers. Such materials, known as thermoelastomers, have been produced commercially for a number of years. However, previously available materials lose their mechanical strength at relatively low temperatures of about 100° C. The University of Massachusetts' thermoelastomers, which use pivalolactone as the basic monomer, retain their mechanical integrity at temperatures approaching 200° C and possess superior mechanical strength at room temperature.

Molecules on Metal Surfaces

A central problem in understanding surface phenomena and catalytic processes is the bonding configuration of adsorbed atoms and molecules. Although this encompasses both geometrical and electronic configuration, it is currently the lack of geometrical information that most seriously limits progress in the field, because catalytic activity depends crucially on the bonding geometry of the adsorbed molecules. In a combined theoretical and experimental program, surface scientists at the University of Pennsylvania have succeeded in demonstrating how the geometrical orientation of simple molecules adsorbed on a metal surface can be unambiguously determined.

The experimental approach employed by these researchers is angular-resolved photoemission spectroscopy. In this technique, polarized ultraviolet light (from the Synchrotron Radiation Facility at the University of Wisconsin) is directed either at free molecules in the gas phase or at the same molecules adsorbed on the metallic surfaces. The incident light excites electrons from the various electronic states within the molecules with an energy sufficient to eject them from the molecules. By measuring the energy distribution of the emitted electrons as a function of angle and of the polarization and energy of the incident radiation, a wealth of information concerning the electronic and geometrical configuration of the molecules can be obtained.

An important key to the problem was the realization that, while the specific electronic structure of the molecules is modified by their interaction with the surface, certain characteristic features of this structure remain unchanged. Thus, the first step in the program was to develop a detailed understanding of the photoemission process in those gas phase molecules of interest to the surface research. E. W. Plummer and T. Gustafsson measured the photoemission spectra for some 10 to 15 molecules, including nitrogen, carbon monoxide, and carbon dioxide, while J. R. Schrieffer and P. Soven developed a theory capable of quantitatively explaining the resulting data. This joint effort in itself has led to a detailed understanding of the photoionization process that represents a major advance in the field of gas phase photoionization. The second step in the program was to modify the theory to take into account the changes introduced in the photoemission when the molecules are adsorbed on a metal surface and to measure the corresponding photoemission spectrum of the adsorbed molecules.

This approach is currently being used to study other and more complex molecules adsorbed on metal surfaces and to investigate their electronic as well as their geometrical properties. At the same time it illustrates a new and potentially fruitful direction for surface and catalysis research, in which the properties of isolated gas-phase molecules are used to obtain insight into related properties involving actual surfaces.

The Formation of Layered Structures

A process to form layered structures, and also amorphous composites and synthetic crystals not observed in nature, is under development at the Materials Research Laboratory at Stanford University by a group led by T. W. Barbee, Jr. These unique materials are of considerable potential interest with respect to their mechanical, magnetic, and superconducting properties.

The synthesis process makes use of physical vapor deposition methods to produce alternate thin layers of different materials on a substrate. The thickness of the layers can be varied from 10 Angstroms to more than 5,000 Angstroms. Whereas most arrangements for growing materials of this type utilize moving sources that deposit the material on a fixed substrate, the Stanford approach involves stationary magnetron sputter sources that deposit the layers alternately on a moving substrate. This technique yields a high rate of deposition of extremely uniform layers and permits improved control of important experimental parameters such as the energy of the incident-sputtered atoms, interaction between source and sample, and substrate temperature.

To date, composite layered structures of a number of different combinations of elements have been prepared having a wide range of layer thicknesses. X-ray diffraction, together with Auger spectroscopy, has been successfully used to determine both the thickness and uniformity of the layers (low angle X-ray diffraction) and the structure within the layers (high angle X-ray diffraction). In general, as in the case of copper-niobium or niobium-tungsten composites, well defined, uniform layers having structures characteristic of each of the two components are produced. These are manmade examples of special, naturally occurring structures in which two periodically alternating phases appear in alloys under certain conditions. These materials had been studied previously by other investigators such as J. E. Hilliard at the Northwestern University, who found that they can exhibit unusual mechanical strength and ductility.

However, when the thickness of the layers is reduced to below approximately 40 Angstroms, unexpected and unusual structures can appear. In the case of both copper-niobium and niobium-tungsten the

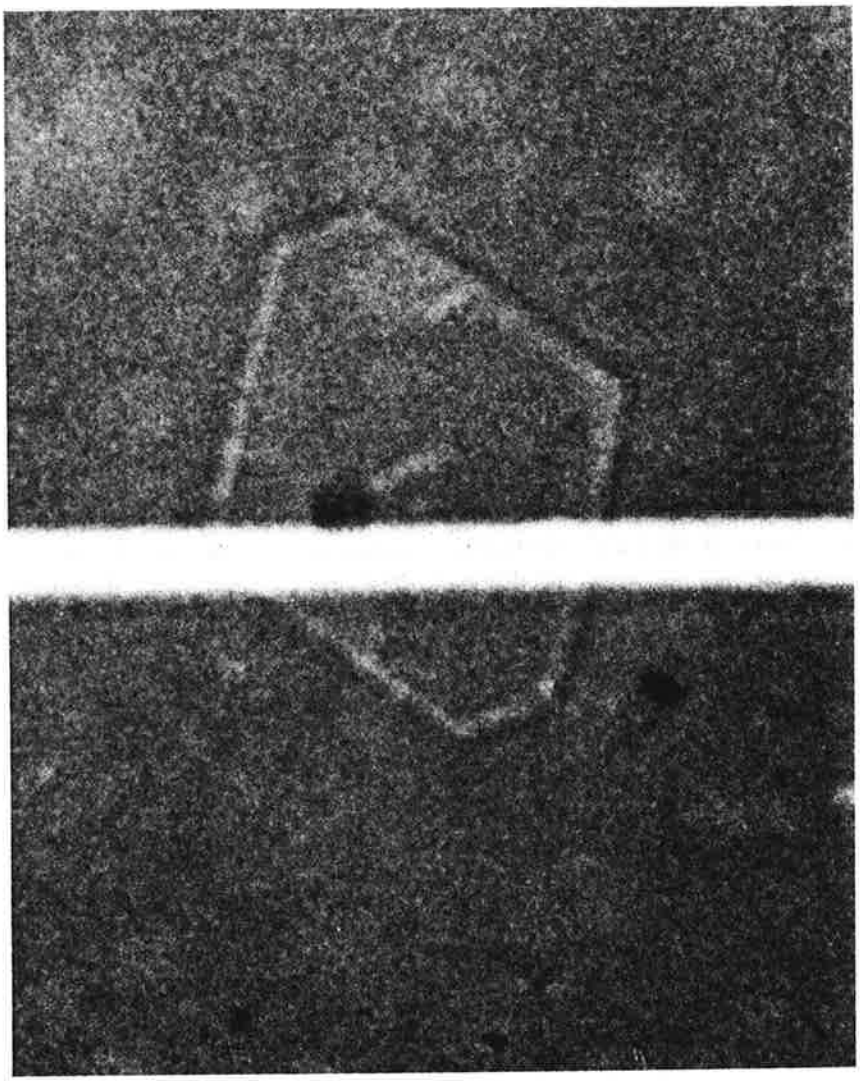
crystal lattices of the two materials influence each other (epitaxy) such that the layered structure no longer exists. The resulting lattice spacing becomes uniform throughout the material and can range anywhere between that of either of the two constituent elements, depending on the relative thicknesses of the layers. Similarly, the electronic properties no longer exhibit a periodic variation, but are uniform throughout the structure. Since copper and niobium are mutually insoluble in the solid state, these synthetic "alloy" crystals represent totally new materials that are not observed in nature. Similar interactions are observed in thin-layered composites consisting of either tungsten or niobium with amorphous materials such as germanium or carbon. In these cases, however, the interaction between the layers can induce the normally crystalline metals to become amorphous also. Again, since these metals are not normally stable in the amorphous state, new materials that do not occur in nature have been produced.

In addition to the interest in the physical properties of these unusual composite materials, they offer potential for important applications such as efficient monochromators and analyzers for X-ray spectroscopy, optical gratings ranging from the infrared to the ultraviolet, and wave guides or "light pipes" for controlling and directing X-rays.

Measuring Tiny Polymer Single Crystals

The simplest morphological entity available to polymer scientists is the polymer single crystal. However, true polymer single crystals are typically only ten wavelengths of light (5 microns) on a side and 50 atoms (0.01 micron) thick—the larger dimension is far less than the diameter of a human hair—and thus their physical properties have not previously been directly amenable to study. So-called crystalline bulk polymers, however, are composed of the tiny, randomly oriented single crystals embedded in an amorphous matrix. Therefore, until now it has been necessary to infer the properties of the single crystals from experiments on these complex polycrystalline, multiphase systems.

At the Case Western Reserve University Materials Research Laboratory, R. Hoffman of the Physics Department, P. H. Geil of the Department of Macromolecular Science, and their coworkers have now



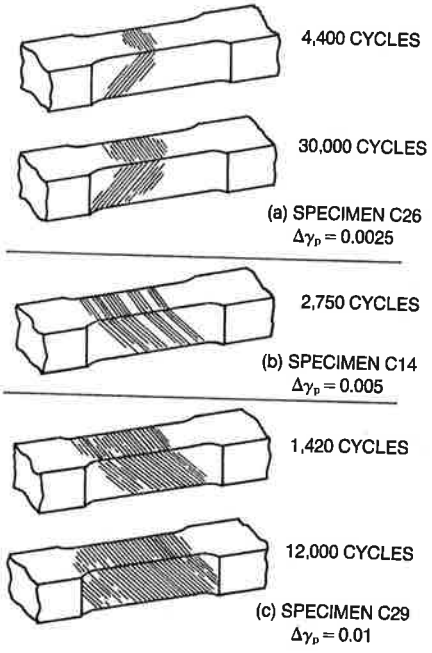
Measuring crystal properties. A newly developed device now permits the direct measurement of mechanical properties of single, microscopic crystals of polymers, important in understanding the physical behavior of these widely used materials. In a "nanotensilometer" this tiny polyethylene crystal, deposited between two movable surfaces, has been pulled to fracture and the force measured. The gap between the surfaces is only three-thousandths of a millimeter. (Photo by Case Western Reserve Materials Research Laboratory.)

developed an instrument capable of measuring directly the mechanical properties of polymer single crystals. Called the nanotensilometer, the instrument is constructed on the concept of an inverted pendulum and consists of two identical platforms that move in concert so that external mechanical vibrations do not affect their relative position. The tiny polymer single crystal is deposited from solution across the gap between the two platforms. The mechanical properties are measured by applying an electromagnetic force, which separates the platforms and stretches the sample. The elongation of the sample is determined from an extremely accurate measurement of an electrical capacitance. The applied force can be measured accurately to a fraction of a dyne, while the smallest displacement that can be measured is 3 Angstroms, or about one atomic radius. It is planned to utilize the nanotensilometer to conduct extensive studies of the mechanical properties of a variety of polymer single crystals. The results of such measurements and their interpretation should be of intense interest to a broad spectrum of the polymer scientific community.

Fatigue of Metallic Materials

If one mechanically loads and unloads (cycles) an annealed metal, initially it hardens rapidly. With accumulating cycles, the hardening rate approaches zero, a condition termed saturation. This is considered prerequisite to crack initiation, which may lead to fatigue failure in service. Current theories of saturation are based on transmission electron microscopy observations of dislocations in the bulk of fatigued samples, yet current understanding of materials behavior under complex loading conditions is very poor. As an example, it is not understood why large loads followed by small cyclic loads are, for certain metallic materials, less damaging than the same loads applied in a different order.

C. Laird and his coworkers at the University of Pennsylvania are trying to understand, as a first step toward the solution of such problems, the mechanism of cyclic deformation of copper single crystals in low strain fatigue. They addressed the question of whether plastic strain in saturation was caused by flip-flop motion of crystalline line defects called dislocation dipoles between equilibrium positions, or by persistent slip bands—concentrated regions of deformation that can be seen on the surface of the crystal as step-like offsets.

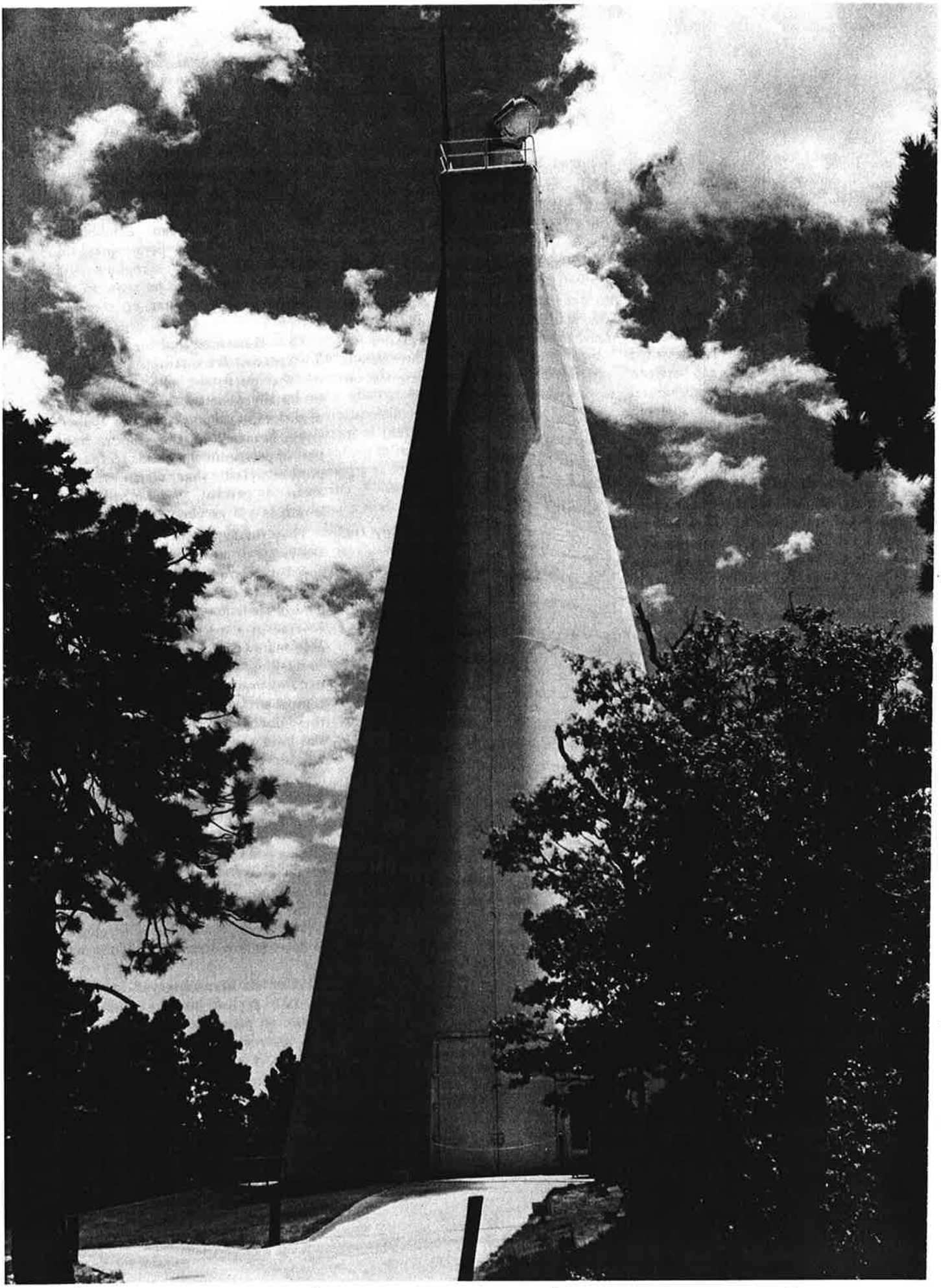


Fatigue deformation. Tensile loading and unloading of an annealed metal results in initial rapid hardening. With increasing cycles, the hardening rate settles to zero; this is considered a prerequisite of crack initiation and is important in failure. In study of a copper sample, it was discovered that for a range of low strains, all strain is carried by slip bands, which appear as lines on the surface. As the applied strain is increased, the volume fraction of slip bands increases. At about 1 percent shear strain the entire sample is a huge (persistent) band. Electron microscopy of these bands has led to a model for low strain cyclic deformation.

They discovered that for a range of low strains, all the strains are carried by the persistent slip bands and essentially none by the dense arrays of dislocation dipoles. As the applied strain is increased, the volume fraction of persistent slip bands increases, until at a plastic shear strain range of about 1 percent, the entire gage length is a large persistent slip band.

They further observed that within the range of strains where persistent slip bands are operating, the stress required to activate them is constant. The observation that bands slip and reverse in a macroscopically observable manner disposed of one of the competing models of fatigue deformation, primarily based on the concept of surface hardening. Moreover, they discovered that the individual slip lines are microscopically reversible, but that, within tight groups of lines, minor irreversibilities occur; these integrate over thousands of cycles to give the notch-peak topography of which the initial fatigue crack consists. This is believed to be the first direct evidence of fatigue crack nucleation. Lastly, by doing additional electron microscopy on the bands, a model was developed to describe low strain cyclic deformation.

What has been observed in single crystals applies to the individual grains of polycrystalline aggregates. The macroscopic stress-strain relationship is more complicated, but a method and direction of research to tackle this complicated problem area has been devised.



Astronomical, Atmospheric, Earth, and Ocean Sciences

2

The reorganization of the Foundation in July 1975 resulted in the combining of NSF's programs in the Astronomical, Atmospheric, Earth, and Ocean Sciences in a single structure to support basic research on the physical environment on Earth and in space. This combining of responsibilities for support of basic research with support of major facilities, national centers, and large-scale research programs is beneficial for making decisions about the allocation of resources within the disciplines and for maintaining overviews and assessing the healths of the various fields.

The overall objectives of the programs are: (1) to obtain new knowledge in astronomy and the atmospheric sciences over the entire spectrum of physical phenomena; (2) to provide a better understanding of the physical and chemical makeup of the Earth and its geological history; (3) to obtain further insights into the oceans' composition, structure, behavior, and resources, and examine the effect of human activities on the ocean environment and vice versa; and (4) to advance knowledge of natural phenomena and processes in the polar regions.

The Foundation furnishes more than half the Federal support to ground-based astronomy in the United States. A project of major importance in this area is the continuing construction of the world's largest and most sensitive radio

Table 2
Astronomical, Atmospheric, Earth, and Ocean Sciences*
Fiscal Years 1974, 1975, 1976
and Transition Quarter (July 1-Sept. 30, 1976)

(Dollars in Millions)

	Fiscal Year 1974		Fiscal Year 1975		Fiscal Year 1976		Transition Quarter	
	Number	Amount	Number	Amount	Number	Amount	Number	Amount
Astronomy	175	$ 9.30	181	$ 10.93	201	$ 11.13	70	$ 4.67
Solar Eclipse Support	1	.04	—0—	—0—	1	.06	—0—	—0—
Atmospheric Sciences	241	12.24	264	13.82	237	14.91	49	2.82
Global Atmospheric Research Program	51	3.86	62	4.04	68	3.81	10	1.00
Climate Dynamics	—0—	—0—	10	1.00	31	1.98	16	1.00
Earth Sciences	274	11.01	296	12.97	296	15.29	117	4.23
Ocean Sediment Coring Program	8	11.08	6	10.50	5	11.83	1	3.50
Oceanography	292	13.34	327	15.28	320	15.65	89	4.54
International Decade of Ocean Exploration	116	13.79	159	14.78	179	15.42	26	3.38
Oceanographic Facilities and Support	86	18.23	86	20.64	70	16.01	14	1.00
U.S. Antarctic Research Program	113	24.74	122	25.90	106	48.58**	89	13.43
Arctic Research Program	46	3.87	35	3.63	46	3.62	7	1.30
Total	**1,403**	**$121.50**	**1,548**	**$133.49**	**1,560**	**$158.29**	**488**	**$40.87**

* Excludes National Research Centers.
** Includes Supplemental Appropriation of $18.0 million for procurement of two ski-equipped aircraft.

Table 3
Astronomical, Atmospheric, Earth, and Ocean Sciences
National Research Centers
Fiscal Years 1974, 1975, 1976
and Transition Quarter (July 1-Sept. 30, 1976)

(Dollars in Millions)

	Fiscal Year 1974	Fiscal Year 1975	Fiscal Year 1976	Transition Quarter
National Astronomy and Ionosphere Center	$ 3.20	$ 3.20	$ 4.05	$ 1.10
Kitt Peak National Observatory	7.80	7.68	8.40	2.15
Cerro Tololo Inter-American Observatory	2.60	2.95	3.45	.90
National Radio Astronomy Observatory	12.10	19.30	21.55	3.50
National Center for Atmospheric Research	17.50	17.45	23.83	4.84
Total	**$43.20**	**$50.58**	**$61.28**	**$12.49**

telescope, the Very Large Array, in New Mexico. This array, consisting of 27 antennas, is scheduled to be completed in 1980 and will provide details of the universe at radio wavelengths that exceed the resolution of ground-based optical telescopes. There is great potential for advances in astronomy in the coming use of this and other new facilities covering several wavelength ranges and giving a more complete physical picture of cosmic objects.

The increasing interest in the chemistry of the lower atmosphere and the stratosphere, particularly the role of fluorocarbons in reducing stratospheric ozone, has focused attention on the Foundation's support for research in the atmospheric sciences. These studies directed at understanding how and why the atmosphere behaves as it does have relied heavily on the increasingly sophisticated computer models supported through the National Center for Atmospheric Research in Boulder, Colo.

In the Earth sciences the plate tectonics theory has provided scientists for the first time with a unifying concept of global structure and composition, a model of how the major features of the Earth's surface have been formed and changed, and the first keys to the basic driving forces of a dynamic and changing planet. The Ocean Sediment Coring Program has played an important part in this effort through drilling and coring in the sediments and upper basement rocks of the world's ocean basins.

In the ocean sciences, marine scientists over the past year have made important discoveries in the movement of the ocean waters, the living and nonliving resources of the sea, and the role of the oceans in shaping weather and climate. Three modern oceanographic research ships have been constructed over the past 2 years to replace worn out ships in the academic oceanographic fleet.

In Antarctica, all management and funding of the U.S. research program there has been consolidated in the Foundation, by order of the President. The peaceful pursuit of science continues in cooperation with 11 other Antarctic Treaty nations. The Foundation is also the lead Federal agency for the extension of research in the Arctic.

Astronomy

The National Science Foundation provides about two-thirds of the Federal support for ground-based astronomy in the United States. In fiscal year 1976, NSF supported astronomers at over 100 universities, private and university observatories, and NSF-supported national observatories. Astronomers at universities and colleges apply to NSF for research grants and to the national centers for observing time on radio and optical telescopes. The number of applicants, the majority from institutions without research quality telescopes, has been steadily rising.

This increasing proposal pressure is due in part to a phasing out of basic research support in astronomy at other agencies. The most recent example is the transfer of responsibility for the Sacramento Peak Observatory from the U.S. Air Force to NSF on July 1, 1976. But the primary driving force behind the surge in astronomy lies in the science itself. This year and in years preceding there were several breakthroughs on the research frontier. As a result, we are now much closer to answering some fundamental questions of astronomy, cosmology, and physics. The point can be illustrated with a few recent examples.

Redshift measurements place the quasar 3C286 at a distance of 22 billion light-years. Last year a team of scientists studied 3C286 and an intervening galaxy with a radio interferometer: the National Radio Astronomy Observatory (NRAO) 300-foot antenna in Green Bank, W. Va., and the National Astronomy and Ionosphere Center (NAIC) 1,000-foot antenna in Arecibo, P.R. These studies provided independent evidence that 3C286 is at least 18 billion light-years away. If quasars are at such cosmological distances, then other measurements of angular motions show that some are moving at speeds exceeding the speed of light. This is, of course, in flat contradiction to the current theoretical foundations of science.

Since 1963, our picture of the universe has been enriched with the detection by radio antennas of spectral radiation from vast clouds of interstellar molecules. Most were found with the NRAO 36-foot millimeter wave antenna, and last year NRAO added the ion DCO^+ to the list. The deuterium (the D in DCO^+) is primordial—having been created very soon after the birth of the universe. Also, a new infrared spectrometer on the Kitt Peak National Observatory (KPNO) 4-meter telescope made the first *optical* discovery of an interstellar organic molecule—acetylene, C_2H_2. We now know of more than two dozen organic molecules in deep space.

During the week of July 4, 1976, the newly upgraded NAIC 1,000-foot antenna, operating as a radar, mapped Martian landing sites for the NASA Viking 1. The new maps allowed NASA to alter Viking's original course—avoiding a possibly disastrous landing in rough terrain. In other areas of solar system

astronomy, progress still depends heavily on ground-based observations. An example is a careful study of transient holes in the Sun's corona, made using a spectroheliogram with the KPNO Solar Vacuum Telescope. For the first time, a one-to-one correspondence was found between the occurrence of coronal holes and geomagnetic storms here on Earth 2½ days later. In another study, observations of the infrared reflection from Pluto indicate that its surface is covered with frozen methane, which is probably left over from the origin of our solar system.

With ever-improving estimates of the age and gross density of the universe, astronomers are coming closer to predicting its ultimate evolution. If the universe is not dense enough, or if it is older than 16 to 20 billion years, it may be "open" and continue to expand forever. Otherwise, it should reverse its present expansion and contract. Astronomers at the Steward Observatory, University of Arizona, using a new image tube developed as part of NSF's instrument program, report spectral observations of huge clouds of gas in what was thought to be empty space between galaxies. Discoveries such as this tend to increase our estimates of the universe's density. At about the same time, another group, at the University of Chicago, reported results of a new radioactive dating technique. Primordial rhenium 187 found in meteorites slowly decays into osmium 187, and measurements of the rhenium 187/osmium 187 ratio indicate the rhenium was formed as much as 18 billion years ago.

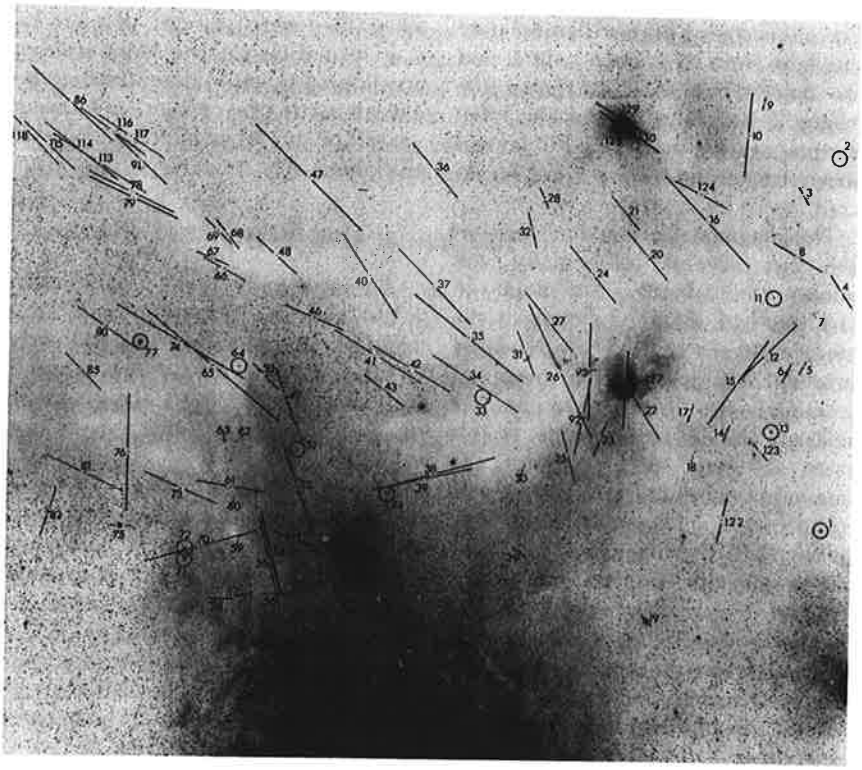
These and other advances sustain an historically recurrent theme. Significant discoveries in astronomy have always followed the use of new instrumentation. As the following pages will bear out, we can now be hopeful that by using a burgeoning variety of new techniques astronomers will give us a far more sophisticated picture of the origin, evolution, composition, and ultimate fate of the universe.

Stellar Nurseries

Stars can form only in the densest, most opaque regions of the interstellar medium. But even though visible light cannot escape from the inner parts of these "stellar nurseries," longer wavelength infrared radiation can penetrate the dense material. The youngest stars in our galaxy, then, are probably detectable only at infrared wavelengths. From this infrared light, astronomers have learned where stars form in our galaxy—but the question of how they form is considerably more complex.

To discover how gas clouds collapse to make new stars, F. J. Vrba (University of Arizona) and his collaborators, S. E. Strom and K. M. Strom (Kitt Peak National Observatory), have recently completed a 2-year study of four star-forming regions. Between 1974 and 1976 they carried out their infrared observations with the 4-meter, 2.1-meter, and 1.3-meter telescopes at Kitt Peak. New detectors and telescope modifications have only recently made such a survey possible.

The first step in the investigation was to pick out four dark clouds which are likely sites of active star formation. The clouds take a variety of shapes that suggest the process by which the cloud is collapsing to form stars. The geometry of the weak



Nursery for stars. Within the collapsing Ophiuclus cloud, where new stars are forming, gas and dust tend to become aligned with the cloud's weak magnetic field. These alignments cause the background starlight to become polarized. Superposed on this Palomar Observatory Sky Survey print are vectors showing the amount and direction of polarization (the numbers signify sky positions only). Magnetic field lines and, hence, regions of condensation follow the polarization lines.

magnetic field in the cloud may play a role in the collapse; the field lines may direct the gas flow, or at least map the flow directions. The collapse mechanism, in turn, may determine the efficiency of star formation in the cloud. To get a complete picture of the star-forming process, then, requires knowledge of a cloud's morphology, magnetic field, and embedded star population.

Surveys at the wavelength of 2.2 microns turned up numerous point sources clustering near the center of each cloud. From counts of these young stellar objects, the astronomers estimated the amount of matter that had actually condensed out of the cloud to form new stars.

If a magnetic field is present, it causes a systematic alignment of the dust grains within the dark cloud. The aligned dust grains then polarize the light from background stars, and the polarization directions map the magnetic field lines. For each cloud, the polarization directions for several dozen background stars were measured.

The magnetic-field geometries imply that several mechanisms can initiate the collapse of a cloud—in fact, each of the four clouds in the study represents a different collapse process. The most efficient means of forming stars appears to be the collision of two dense clouds. In this case, at least 28 percent of the original cloud material condensed to form stars. Dynamic pressures, rather than the magnetic field, have the major influence on the cloud's evolution. A second cloud, whose collapse was initiated by the passage of a shock wave through the gas, had produced stars at an efficiency of 8 percent. Another cloud gave evidence of collapse induced by a magnetic instability. Most of its stars have formed at the bottom of a "magnetic well." Here, the cloud material and the magnetic field are locked together, and the field plays a dominant role in the cloud's evolution. The fourth cloud is simply undergoing a quiescent gravitational collapse. Its magnetic field is not strong enough to prevent the collapse, and the cloud material has pulled the field along with it as it collapsed radially.

There appears to be no correlation between the strength of the magnetic field and the efficiency of star formation. Instead, the most important factor is the collapse process. The first two mechanisms, involving strong dynamic pressures, result in extremely efficient star formation. The latter two processes, which are more quiescent, have much lower efficiencies; only 1 or 2 percent of the cloud material condenses into new stars.

These are the first observational answers to the question of how stars are made. Vrba's results will help solve the more general problem of star formation on the large scale, a crucial step toward understanding the overall structure of our Milky Way and all of the other billion galaxies in the observable universe.

The Magellanic Plane

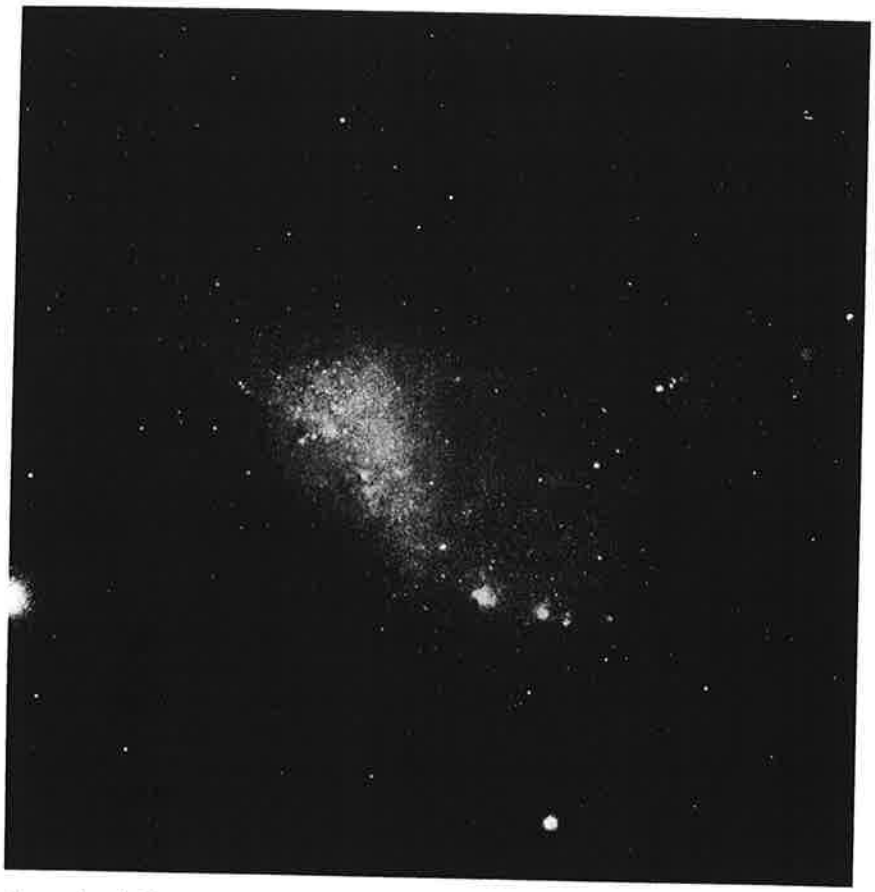
A recent study at the Cerro Tololo Inter-American Observatory (CTIO) has contributed to an understanding of the violent interaction between our own Milky Way Galaxy and its closest neighbors, the Magellanic Clouds.

In the Milky Way, globular clusters—each one a spherical concentration of hundreds of thousands of stars—are scattered in a roughly spherical distribution enveloping the Milky Way. Most such clusters bear a basic resemblance to one another, because they were all formed at about the same time and, therefore, comprise similar populations of stars. This similarity can be seen readily by plotting the colors of all stars in the cluster versus their brightnesses. In the resulting "color-magnitude" plot, the stars in each globular cluster trace out very similar patterns. The stars are not distributed over the plot at random, but instead lie along well defined bands according to their intrinsic brightness.

However, when CTIO staff astronomer W. Kunkel, in collaboration with Canadian astronomer S. Demers, plotted the color-magnitude diagram of a distant globular cluster in the constellation Reticulum, they found it to be unlike any of the known globular clusters in our galaxy. First, the band of the diagram traced out by the giant stars is steeper than the analogous branch for most clusters. Second, the Reticulum cluster has an unusually large proportion of bright red stars. Searches for other such objects have disclosed five more globulars with the same features. All of these anomalous systems are at extremely large distances from the galactic center, greater than 480 trillion miles.

Five of the six share a further property: projected onto the sky, they lie within a few degrees of a great circle, as if confined to a plane. Significantly, the same great circle also passes through our nearest neighbor galaxies, the Large and Small Magellanic Clouds and the band of hydrogen gas connecting them. The probability that such a distribution might arise by chance is less than 0.002. Kunkel and Demers thus concluded that the Magellanic Clouds and the anomalous globular clusters are all part of a real "Magellanic Plane Group."

Suspecting that the peculiar clusters may be relics of a close encounter between the Magellanic Clouds and our galaxy, Kunkel computed models of the hypothesized interaction. The computer produced a "moving picture" of the disruption suffered by the Magellanic Clouds during a close orbital pass around the galaxy. Kunkel concludes that enough of the outer material of the Magellanic Clouds could have been stripped off to form the "Magellanic stream" of hydrogen gas and the



Nearest neighbor. The Small Magellanic Cloud is a satellite to our own Milky Way Galaxy and is visible to the naked eye in the Southern Hemisphere. Peculiar globular clusters recently observed at Cerro Tololo Inter-American Observatory suggest an encounter between the Cloud and our Galaxy. The close encounter may have stripped off the outer material of the Cloud to form peculiar objects in the Magellanic stream and plane.

anomalous globular clusters. The peculiarities of the clusters may thus be due to their relatively young age.

Radar Mapping of the Surface of Venus

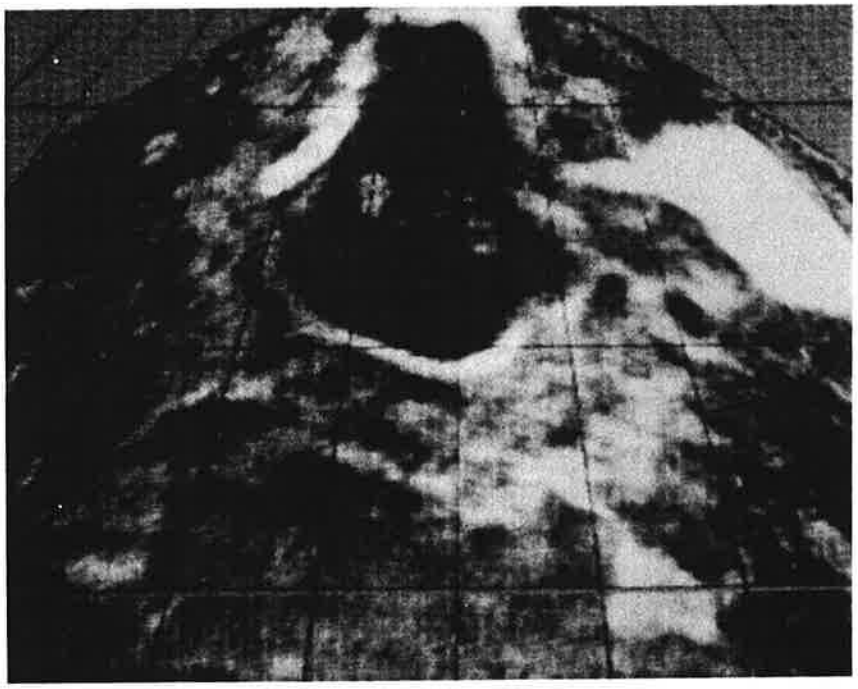
The first detailed pictures of a large portion of the surface of the planet Venus were obtained at the National Astronomy and Ionosphere Center during the year. Successfully piercing the cloud cover of the planet, the pictures show evidence that processes at work on both the Earth and Moon are also acting on Venus. The pictures were made with the new S-band radar system by D. B. Campbell and R. B. Dyce of the NAIC staff, and G. H. Pettengill of the Massachusetts Institute of Technology. To obtain clear and unambiguous pictures, the scientists had to use the NAIC 1,000-foot telescope in conjunction with a 100-foot steerable antenna located 6 miles north of the main observatory. These are connected by a microwave radio link, and each telescope possesses an extremely sensitive solid-state maser that has the required signal-to-noise ratio characteristics for the mapping observations. The radar echoes of the S-band radar transmissions were measured by both antennas to determine precisely the time of arrival, intensity, and frequency of the returning pulses. This information was then used to determine the exact locations of the echo-regions and the strengths of reflected signals.

The first observational results gave a picture of a region of Venus of about 4 million square miles in area. The region extends 80° in longitude and from 46° to 75° north latitude. The horizontal resolution in the pictures is about 12 miles.

Two major features appear in this region. One is a large basin extending about 1,000 miles in the north-south direction and 600 miles in the east-west direction—approximately the size of the Hudson Bay. Its southern, northern, and northwestern boundaries are bright rims which appear to be formed by a series of sharp ridges several hundred miles long. To the south of the basin there is a region of greater brightness. This area has the same appearance as the ejecta blankets of some lunar craters, places covered with debris that was thrown out when large objects impacted the lunar surface. Two smaller craters are located within the basin.

To the east of the basin is a very large bright area about the size of the State of Oklahoma. This region, previously detected at Arecibo and named "Maxwell," is a very rough elevated plateau comprised of long parallel ridges and canyons extending for hundreds of miles. No feature like this exists on either the Earth or the Moon. It seems to overlie an older surface and cannot be the result of meteoric impact. Scientists believe the feature is the result of processes internal to Venus, possibly the result of a large eruption of lava.

The feature "Maxwell," along with the bright rims of the adjacent basin, appears to be the result of tectonic or mountain-building activity on Venus similar to that which has shaped the



Through the clouds. This radar map of the surface of cloud-shrouded Venus, made at the National Astronomy and Ionosphere Center, reveals a large basin about the size of Hudson Bay. The basin is believed to be caused by the impact of a large object. The extensive bright region adjacent to the basin has the same appearance as the debris blankets near lunar craters that were formed by impacts.

surface of the Earth. The large basin, on the other hand, is reminiscent of large impact areas, similar to the maria of the Moon. Thus, it appears that processes which shaped both the Earth and Moon were active at some point during the evolution of Venus.

Pulsars Rocketing Through Space

Since the first pulsar was discovered in England in 1968, more than 150 have been detected, and one-third of them have been found by the radio astronomers at the University of Massachusetts. The pulsars are superdense collapsed stars, about 15 kilometers in diameter, but with masses like that of the Sun. They are spinning, perhaps a thousand times a second early in their lives, and have highly intense magnetic fields, reaching one trillion times the Earth's field, all as a result of the collapse. They radiate intense pulses of radio waves into space.

By carefully examining the arrival times of radio pulses emitted by a pulsar over 1,000 light-years away, David J. Helfand, Joseph H. Taylor, and R. N. Manchester of the University of Massachusetts have determined that it is rocketing through space at over 550 kilometers per second, or 1¼ million miles per hour.

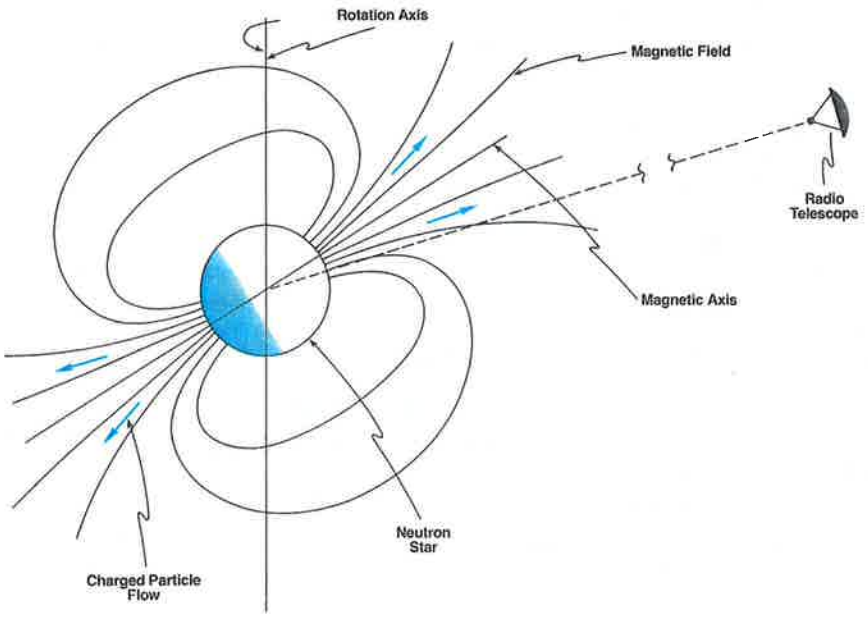
The observers record signals from many pulsars several times a week at the Five College Radio Astronomy Observatory in central Massachusetts. The time at which the pulses reach the telescope after traveling through space for hundreds of years depends on where the Earth is in its annual path around the Sun. To avoid the confusion of getting different results during different seasons, the astronomers correct the arrival times to an imaginary stationary observatory at the center of the solar system. This correction, however, depends on knowing the position of the pulsar in the sky very accurately. If this well determined location changes because the pulsar is moving, a steadily increasing error is seen in the pulse arrival times, from which the pulsar's velocity can be computed. Several sources have been clocked in this way, yielding velocities ranging from 50 to over 500 kilometers per second.

Radio astronomers at two other observatories have recently obtained similar results using the more traditional technique of measuring positions by radio interferometry. The motions across the sky of ten pulsars have now been determined; at least three are moving so fast that they will eventually escape the gravitational pull of our galaxy and will speed off into the vast emptiness of intergalactic space. Most of the sources are moving away from the Earth, as would be expected if the pulsars are born in the violent collapse of giant stars near the galactic plane.

The Massachusetts radio astronomers and their colleagues are examining various mechanisms to explain the acceleration of the pulsars to high velocities soon after they are born. During their investigations they noticed a strong correlation between a pulsar's velocity and the estimate of the strength of its magnetic field at birth. The sources with weak fields all had low velocities (100 kilometers per second), whereas those with strong fields had a wide range of speeds up to nearly 1,000 kilometers per second. This relationship suggested an electrodynamic origin for the pulsar velocities. Such a model was proposed last year by E. Tademaru and E. R. Harrison of the University of Massachusetts. It views the rapidly rotating, newborn pulsar

as a photon rocket. The radiation force that provides the acceleration results from the slight displacement of the centroid of the huge magnetic field from the center of the star.

This new work on pulsars has helped establish the velocity distribution of these sources, an essential clue in interpreting their observed distribution in the galaxy.



Pulsar model. A pulsar is a rapidly rotating, very dense neutron star less than 15 kilometers in diameter. Charged particles, escaping from the surface along magnetic field lines near the magnetic axis, radiate a beam of energy in the radiofrequency range. These radiations are detected on Earth as pulses each time the beam sweeps through the Earth's line of sight.

National Astronomy and Ionosphere Center

The National Astronomy and Ionosphere Center, operated and managed by Cornell University under contract with NSF, provides unique facilities for visitor-oriented research programs in aeronomy and radio and radar astronomy. The main instrument is the world's largest single radio/radar telescope. This device, incorporating a 1,000-foot diameter fixed spherical antenna, is located in a remote, radio-quiet valley 12 miles south of the city of Arecibo, P. R. NAIC provides telescope users with administrative, engineering, and technical support for their observing programs. The NAIC headquarters are located on the Cornell campus in Ithaca, N.Y.

In September 1976, Cornell University ended a nearly 5-year subcontract effort to upgrade the surface of the 1,000-foot reflector. E-Systems, Inc., of Dallas Tex., the resurfacing subcontractor, completed several complex tasks during the past several years, including: the arrest of extensive ground subsidence on the dish perimeter; diagnosis and correction of a difficult surface flexure problem; and the design, fabrication, and installation of 38,778 precision aluminum panels. Cornell is presently preparing a plan to complete the final alignment with Cornell/NAIC staff using a new laser survey system. Alignment completion is scheduled for late fiscal year 1977.

Several important accomplishments during fiscal year 1976 were made using the 2,380-megahertz planetary radar system. These included the high-resolution mapping of the cloud-covered surface of Venus, the mapping and analysis of NASA-Viking Lander sites on Mars, and the detection of the asteroid 1580 Betulia. These observations were made possible by the new remote 100-foot diameter interferometer antenna located 6 miles from the main observing site, which forms an interferometer with the 1,000-foot antenna.

A long-sought development in aeronomy was the first detection of an incoherent backscatter echo from free electrons in the ionosphere. The detection of this ionospheric electron component was the primary goal that led to the establishment of NAIC more than 15 years ago. This result was possible because of the availability of a sensitive, broad-band 4096-channel autocorrelator that was designed and built for the S-band planetary radar program.

During fiscal year 1976, the NAIC radio/radar telescope was used by 64 visiting investigators from 30 domestic and foreign research and educational establishments. The number of visiting scientists was 68 percent larger than in the previous year. During the year, 72 percent of the observing time on the large reflector was allocated to radio astronomy, 16 percent to ionospheric studies, and 12 percent to radar astronomy.

National Radio Astronomy Observatory

The National Radio Astronomy Observatory is operated and managed by Associated Universities, Inc., under contract with the Foundation, from scientific and administrative headquarters located in Charlottes-

ville, Va. The observatory is equipped with four radio telescope systems—three at the principal observing site at Green Bank, W. Va., and one on Kitt Peak, near Tucson, Ariz. Early in fiscal year 1977, research operations will begin with the partially completed Very Large Array (VLA), an NRAO project for a 27-element radio telescope capable of imaging celestial radio emitters. The VLA is located on the Plains of San Augustin, 50 miles west of Socorro, N. Mex.

During the past year a total of 270 visiting observers (including 75 students) representing 83 institutions used the NRAO telescopes. A new feature of the 1976 program was use of the 140-foot telescope at Green Bank in a network of telescopes performing simultaneous observations over transcontinental baselines. This multistation, very long baseline interferometer, which provided a resolution at least 100 times that of existing optical instruments, was used to study the fine structure in radio sources. The most complex of these experiments involved telescopes at eight locations.

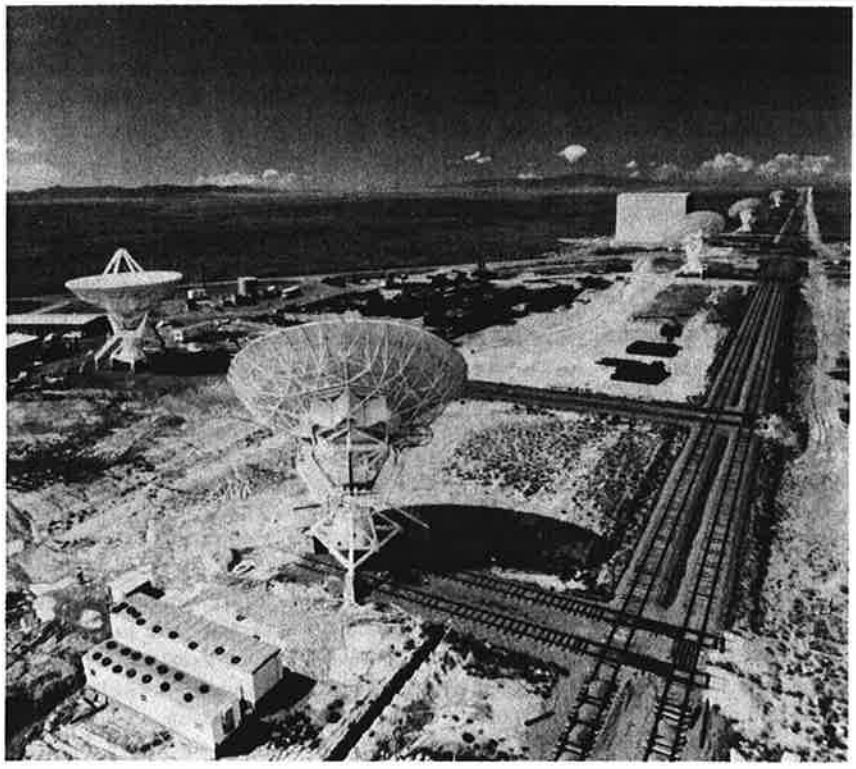
Two new "front-ends" have been added to the 36 receivers available at the NRAO telescopes. These are a 3,120-3,370 megahertz dual-channel cooled parametric amplifier system and a combined 1,000-1,450 megahertz and 4,500-5,000 megahertz dual-channel up-converter/parametric amplifier system. Both systems were tested on the Green Bank telescopes in the late summer of 1976. A combined 80-120 gigahertz/33-50 gigahertz cooled-mixer receiver is nearing completion, and work is in progress on a number of maser systems.

Preliminary operations and testing of the VLA began October 24, 1975, when the first antenna completed for the 27-antenna array was placed in operation. Since that time, a total of six antennas has been completed, and three of these are now being used as an interferometer to test the central electronics and computer systems in the control building. Of the six major site structures, only the visiting scientists quarters remain to be completed. With the completion of the second increment of wye track construction in September 1976, 1.1 miles of the north arm, 1.2 miles of the southeast arm, and 6.5 miles of the southwest arm will be available for the start of research operations. The VLA is scheduled to be completed in fiscal year 1981.

Kitt Peak National Observatory

Kitt Peak National Observatory, located in southern Arizona, is operated by the Association of Universities for Research in Astronomy, Inc., under contract with NSF. As a national center, it makes first-rate research facilities available to astronomers throughout the country. Sixty percent of all telescope time is reserved for visiting astronomers, who are awarded time on the basis of their research proposals. The remaining 40 percent of the time is allocated to resident staff members, who carry out their own research programs and supervise the development of new equipment.

Two of the optical telescopes are designed especially for solar observations; the other nine are used for studies of planets, stars, interstellar material, and external galaxies. The telescopes range in size from 4 meters (the second largest reflector in



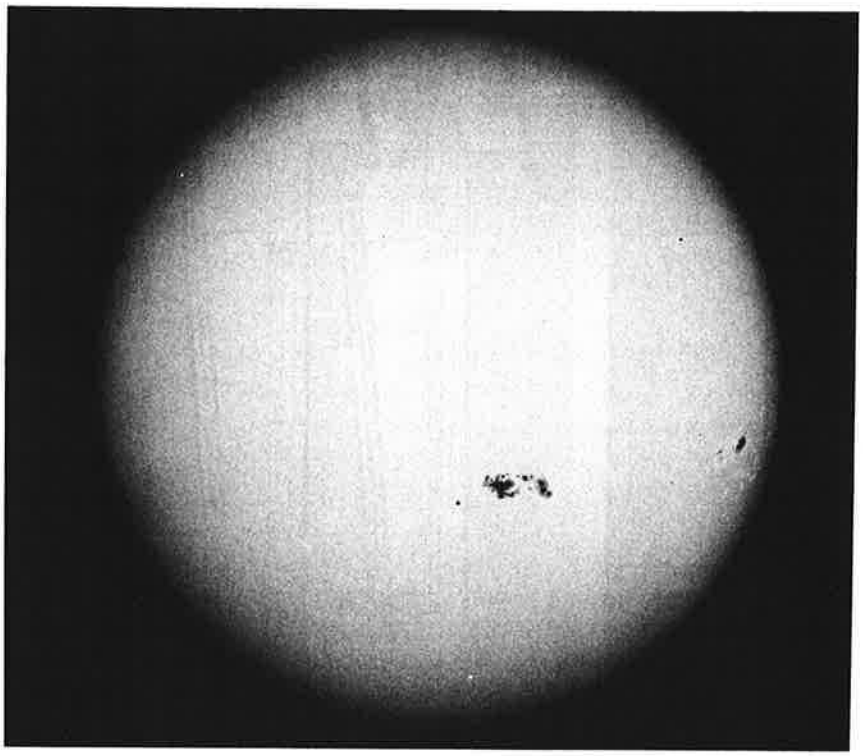
Under construction. At the site of the Very Large Array in New Mexico, the fifth antenna of an eventual 27-element radio telescope nears completion. This view looks along the southwest arm of the wye-shaped tracks on which the antennas can be positioned. When completed in 1981 it will be the world's most sensitive radio telescope and able to detect never-before seen facets of the universe.

the country) to 31 centimeters. Each has special functions. The 31-centimeter Schmidt, for example, is ideal for wide-field surveys and comet photography; the 4-meter telescope is reserved for faint-object astronomy.

During the past year the observatory has placed greatest emphasis on developing new ways to make the best possible use of this array of telescopes. Two Fourier Transform Spectrometers installed at the 4-meter telescope and at the McMath Solar Telescope will allow faint objects to become accessible and brighter objects to be observed in a fraction of the time required previously. KPNO also supports an active program to develop the best available detectors for both visible and infrared radiation. Modern detectors have been crucial to the success of the observatory's new spectrometers.

During an observing run, computers programmed with new software can control the telescope motions with precision—of special importance to daytime observations at infrared wavelengths. The computers can also handle an unprecedented amount of data at several stages: acquisition from the detector, on-line reductions during the observing session, and later analysis at the downtown offices.

During fiscal year 1976, 278 visiting scientists from 77 U.S. institutions and 10 foreign countries observed with KPNO telescopes.



Taking the Sun's temperature. The amount of sunlight reaching the Earth affects our climate and is directly responsible for all life as we know it—yet we don't know how constant this radiation really is. A study under way at Kitt Peak National Observatory to monitor the Sun's brightness may provide new insight into climate-changing mechanisms. This view of the solar surface was obtained with the McMath Solar Telescope.

Cerro Tololo Inter-American Observatory

The Cerro Tololo Inter-American Observatory is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation. Located in the Chilean Andes at a southern latitude of 30°, CTIO is the Southern Hemisphere counterpart of the Kitt Peak National Observatory. Its site atop a 2,200-meter mountain is one of the finest in the world for astronomical observations. The observatory headquarters, located in the coastal city of La Serena, include a library, a computing center, engineering and technical facilities, and staff housing.

During fiscal year 1976, special attention was given to preparing the 4-meter telescope for visitor use. The prime focus was made available to visiting scientists in January of 1976, and later in the year the Ritchey-Chretien spectrograph and direct camera were also in use.

Work has continued to improve the usefulness of all eight telescopes sharing the mountaintop. In particular, more sensitive detectors have been tested, and computers are now used for telescope control and data acquisition. The computer control system for the 4-meter telescope was recently completed, and the pointing accuracy of the telescope is now better than 2 seconds of arc.

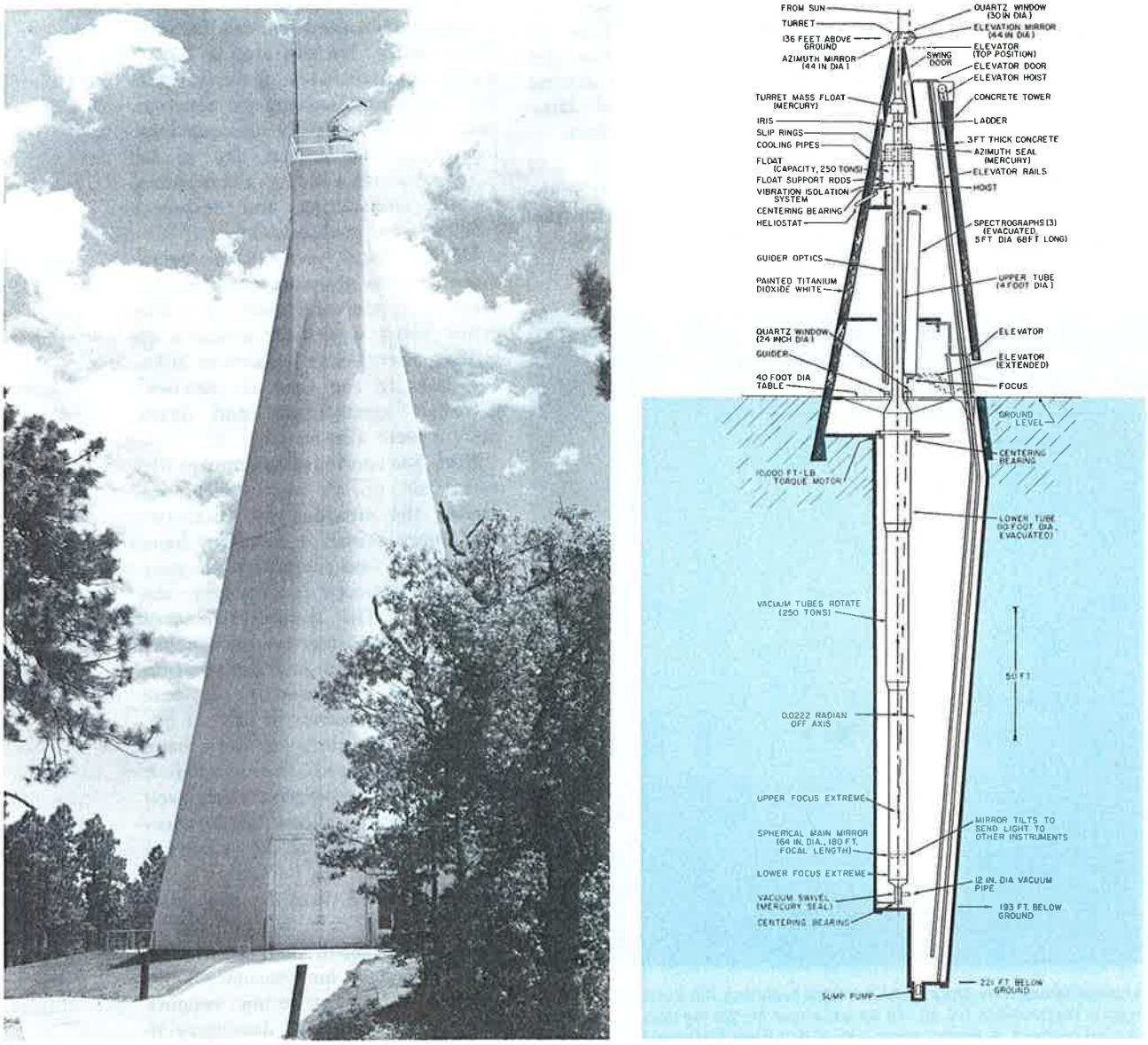
Other observatory services have also been improved. The installation of frequency conversion equipment on Cerro Tololo allows interconnection to the commercial electrical power service. In La Serena, an instrument and maintenance shop was completed; this will be used to fabricate and repair instrumentation under the close supervision of the scientific and engineering support staff. A new ten-unit dormitory is now available for visiting observers using the computer and other facilities at the headquarters.

To improve the administrative efficiency of observatory operations, a scientific programs division has been established. Managed by a support scientist and a steering committee of staff scientists, the division is now responsible for the operation of all telescopes.

Sacramento Peak Observatory

The Sacramento Peak Observatory, operated under contract with NSF by the Association of Universities for Research in Astronomy, Inc., provides unique instrumentation and facilities for advanced research in solar physics and related disciplines. The SPO facilities are located at an elevation of 9,200 feet in the Sacramento Mountains of south-central New Mexico.

On July 1, 1976, responsibility for SPO was transferred from the U.S.



Solar physics. The 7-year-old Solar Vacuum Tower Telescope at Sacramento Peak Observatory in New Mexico provides critical data about solar flares, magnetic fields, and the velocities of matter in the solar atmosphere. Its 30-inch fused quartz entrance window is 136 feet above ground level, and the bottom of the evacuated optical system is 193 feet below ground.

Air Force to NSF. In fiscal year 1977, the USAF is funding 50 percent of the SPO operational costs, which are estimated at $1.5 million. In fiscal year 1978 and fiscal year 1979, the USAF will provide $325,000 each year.

AURA, the NSF contractor responsible for SPO, will operate and manage SPO during a 15-month interim period, extending through September 30, 1977, while NSF selects a permanent operator. An *ad hoc* committee of scientific and business experts was established in June 1976 to advise NSF on operational matters and long-range programs at SPO, including a proposed management structure. The committee is expected to report by January 1977.

The principal instrument at SPO is a 357-foot high solar vacuum tower telescope with an echelle spectrograph, digital diode array, and universal birefringent filter; it is capable of producing simultaneous real-time images of the Sun in widely separated wavelength bands. Other instruments include two 40-centimeter aperture coronagraphs, a 40-centimeter telescope with a solar magnetograph, and several smaller instruments designed for polarization measurements and other studies. Telescope users are provided with data reduction services that include a computer, a microdensitometer, a blink comparator, and a measuring engine. During fiscal year 1976, while under the aegis of the USAF, SPO facilities were used by 30 investigators from 24 domestic and foreign research and educational institutions.

Atmospheric Sciences

The Foundation's research programs in atmospheric sciences have as their goal the increase of knowledge and understanding of the behavior of the Earth's atmosphere. The realm of atmospheric sciences begins at the surface of the Earth where the atmosphere interfaces with the land and the waters and continues to the outer reaches of space where it merges and interacts with the atmosphere of the Sun. To study such a vast regime calls for talents from many disciplines. Atmospheric sciences, therefore, is itself a derived discipline in which the basic knowledge from physics, chemistry, mathematics, biology, and other sciences is applied in various ways and through many techniques to improve our understanding of how and why the atmosphere behaves as it does.

One of the best recognized applications of our understanding is to weather forecasting. It might be said that all these studies in atmospheric sciences, which are aimed at improving our fundamental knowledge about the physical system of the Earth's atmosphere, have as their ultimate goal the improvement of weather forecasting, even though only a few of them are intended to contribute directly to that process.

However, the research supported by NSF may contribute directly to the solution or alleviation of such atmospheric problems as those associated with pollution from major industries, growing population, and other societal actions that affect the atmosphere in various and subtle ways. The problem of drought, for example, has assumed major importance recently because of its relation to the availability of water and thus to crop yields and food production. Unfortunately, little is known about the cause or causes of drought or why certain lands can support a good crop in some years and in other years suffer from a drought. Certainly the drought problem is associated with changes in the general circulation of the atmosphere, but we do not know why changes take place in the general circulation. Modeling and simulation studies plus sensitivity analyses and diagnostic studies are helping to unravel the problem, but it will take many years until the causes are identified and future drought conditions can be reliably forecast. At this time, a concentrated effort is under way nationally and internationally to understand better the general circulation of the atmosphere. The payoff from this study will be better and longer range weather forecasts.

Severe storms such as tornadoes and large thunderstorms that bring hail, lightning, and high winds cause a great deal of damage in the United States. Again, very little is really known and understood about these systems. Why do they form? Where and when will they strike? An increasing amount of NSF-supported research in the atmospheric sciences is directed towards studies of these severe weather phenomena and methods to analyze the results of field studies.

There are three basic atmospheric research programs—solar-terrestrial, aeronomy, and meteorology. Two other programs—the Global Atmospheric Research Program (GARP) and climate dynamics—are multidisciplinary and components of interagency and international programs. All of these programs support fundamental research through grants to individual investigators, most of whom are located at universities.

The National Center for Atmospheric Research, with headquarters and facilities in Boulder, Colo., sup-

ports a broad spectrum of research in atmospheric sciences. In addition it provides facilities, such as a major computer, aircraft, and a scientific balloon-launching facility (in Palestine, Tex.), that are too large or expensive for an individual institution to maintain.

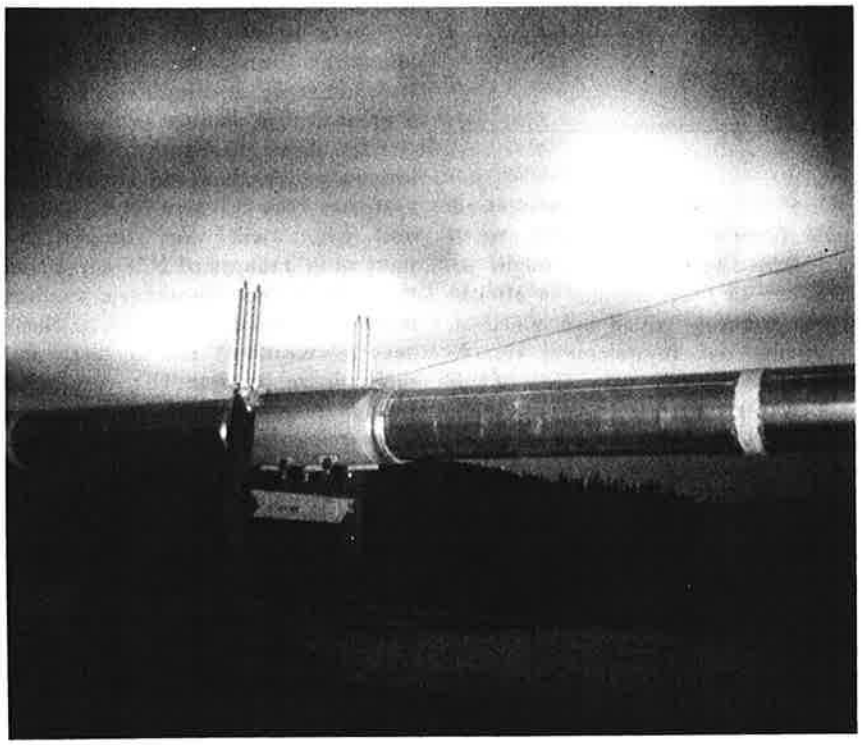
International Magnetospheric Study

The magnetosphere is a region of our near-space environment, controlled by the extension of the Earth's magnetic field, in which the flux of energetic particles from the Sun causes some of the more dynamic upper atmospheric phenomena, such as magnetic storms and auroras. One of the major purposes of the current International Magnetospheric Study (IMS)—a coordinated, international, cooperative research program—is to understand the solar influence on the atmospheric - ionospheric - magnetospheric interaction. For example, it is well known that electric currents of many millions of amperes, originating deep in space but inside the magnetosphere, impinge on the polar upper atmosphere, pass through the ionosphere, and return to the magnetosphere. These currents are enhanced during polar substorms, which in turn appear to be triggered by the solar magnetic field. It is the purpose of the IMS to study these phenomena through coordination of ongoing programs and by taking advantage of unique spacecraft opportunities available during 1976-79.

The key ingredients of the IMS are a multination list of spacecraft; new ground-based instrument arrays, some of which will greatly advance international data exchange standards by using simultaneous data collection, processing, and dissemination in real time at an existing central data facility; incoherent scatter radars; the Satellite Situation Center, which keeps scientists informed about the status of satellites and experiments; and a variety of ground-based balloon, rocket, and aircraft experiments. While the IMS requires some new facilities and support, it is based primarily on the effective use of presently planned programs.

In fiscal year 1976 NSF's solar-terrestrial and aeronomy programs funded major portions of the ground-based networks. The magnetometer network represents the highest priority item and is being acquired with cooperation from the National Oceanic and Atmospheric Administration and the U.S. Geological Survey. The installation, calibration, and operation of the magnetometers will be handled by various university groups. In fiscal year 1976 only one group, at the Geophysical Institute, University of Alaska, was funded to initiate work at the remote sites in Alaska. Other university groups will install units in North America and a few Pacific islands during fiscal year 1977. The magnetometer network will be dense enough to permit estimation of ionospheric currents with previously unobtainable accuracy. Associated with the network of magnetometers will be riometers (instruments designed to measure the radio absorption in the upper atmosphere due to energetic particle bombardment). These instruments were constructed during fiscal year 1976 and will be installed in high latitude sites during fiscal year 1977.

Three groups have been funded to install a coordinated network of sky-scanning auroral photometers across the northern United States, Canada, and Alaska. These photometers are designed to map atmospheric light



Northern lights. Auroras, such as this one seen from the route of the Trans-Alaska Pipeline, result from the interaction of particles from the Sun and the Earth's atmosphere. Learning more about this solar influence is the purpose of the International Magnetospheric Study.

emissions from the upper atmosphere at several wavelengths selected to give maximum information about the physical processes responsible for the emissions. The particular processes of interest here are those concerning energy from auroral protons, electrons, and fields coming from the magnetosphere. Most of the construction of these photometers was funded in fiscal year 1976. Fiscal year 1977 funds will permit the installation of these units in the field and the beginning of data analysis and dissemination.

Only a few field experiments were supported in 1976, although this activity is expected to increase vigorously as IMS progresses. Two very low frequency (VLF) experiments were funded in 1976, the first of which has already completed its field operational phase. This involved the injection of VLF radio energy into the ionosphere over New Zealand using a high-powered, ground-based transmitter and a balloon-borne antenna. The VLF emissions were transmitted through the magnetosphere and received at Cold Bay, Alaska. The modulation of the VLF emissions by magnetospheric plasma allows them to be used as a diagnostic tool for probing the upper atmosphere. The data from this campaign (Operation Skyhook Kiwi) are now being analyzed by scientists at the Aerospace Corporation in conjunction with similar data obtained from Air Force satellites.

Another major component of the IMS is incoherent scatter radar, a radar technique that detects and analyzes radar returns from individual ions in the atmosphere to study a variety of static and dynamical processes. The United States supports three incoherent radar installations: The National Astronomy and Ionosphere Center near Arecibo, P.R., the Millstone Hill Facility in Massachusetts, and the Chatanika Radar in Alaska. Partial support is also provided for the Jicamarca Radio Observatory in Peru. The two northernmost U.S. radars (Millstone Hill and Chatanika) are being funded for campaigns oriented towards the IMS. Millstone Hill will receive a new (Department of Defense surplus) steerable dish antenna that will considerably enhance its power as a research tool. Chatanika already has received new electronic hardware. Also, Chatanika has recently demonstrated an ability to measure winds in the troposphere and stratosphere, a previously unexpected capability that will be exploited during the IMS for studies of the coupling between the magnetosphere, the ionosphere, and the atmosphere.

In summary, the IMS is making maximum use of existing facilities with a minimum of new funding for a coordinated study of one of the most fascinating regions of the Earth's environment. The development of new methods for the rapid acquisition, processing, and dissemination of data will increase our knowledge of the natural environment and our ability to conduct worldwide research programs.

Composition of Solar Flares

Solar flares—the most violent of nearby cosmic phenomena—are thought to be explosive releases of magnetic energy which eject hot gas (plasma) and energetic particles into the space between the Earth and the Sun. Both the plasma and the particles can reach the Earth's environment, causing severe atmospheric disturbances.

Using data obtained by NASA satellites (IMP 4, 5, and 8), John Simpson and colleagues at the Enrico Fermi Institute of the University of Chicago have been able to show that these flares eject energetic particles that are preferentially rich in the elements heavier than hydrogen. While the Sun is composed largely of hydrogen, it appears that the flare process tends to select heavier elements for acceleration and ejection. An even more surprising result of the most recent analyses is that the flare-generated energetic particles are especially rich in the iron group of elements (mostly iron, but possibly including some nickel). These are important results that will provide a clue to the detailed mechanism by which the flares obtain their energy.

Alaskan Volcanic Emissions

The volcanic peak on St. Augustine Island in Alaska began its fourth major eruption of the century on January 24, 1976, producing heavy ashfalls on Homer and Anchorage (60 and 180 miles north of the volcano, respectively). Immediately following this eruption, the cloud physics group at the University of Washington requested funds to obtain airborne measurements from the emissions of St. Augustine. This request was approved and on February 7 the University of Washington atmospheric research aircraft was on site in Homer. During the next 11 days, ten research flights were made and a unique set of particle and gas measurements was obtained in the emissions from St. Augustine.

The plume from the volcano was very dense and produced almost complete darkness within the aircraft cabin during penetrations. The particles in the plume also caused considerable wear on the aircraft (for example, 1/1000 of an inch was removed from each propeller). A preliminary analysis of the data shows the rate of particle emissions from the volcano ranged from 1,000 kilograms per second to a staggering one million kilograms per second. These figures indicate that worldwide volcanic emissions are much higher than previously estimated and must play a significant role in global pollution and climate variability through a change in radiational characteristics of the atmosphere.

Mt. St. Augustine, Alaska. Although an eruption of this size, which occurred in February 1976, is significant primarily for its local atmospheric pollution, major eruptions (like Krakatoa in 1883) can pollute entire hemispheres of the Earth. (Photo by University of Washington.)

Circulation in the Tropical Troposphere

Preliminary analysis of data from the combined satellite and balloon Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE) has given scientists from the National Center for Atmospheric Research (NCAR), the University of Wisconsin, and NASA a first look at some phenomena of the atmospheric circulation at a level of about 14 kilometers in the upper tropical troposphere. The circulation differs markedly from that in temperate latitudes at similar altitudes. One characteristic is an apparent interhemispheric exchange of air at the altitude at which the balloons were flown. Other results include the detection of long-period gravity waves and deep convective circulations and the ability of the balloons to act as sensitive probes of turbulent diffusion in the upper troposphere and lower stratosphere.

In TWERLE, 411 superpressure, constant-level balloons were launched over a period from May 1975 to January 1976, 272 from sites in the tropics and 139 from Christchurch, New Zealand. The balloons carried an array of sensors to detect pressure, temperature, and balloon altitude; these data were transmitted to a receiver aboard the Nimbus 6 satellite each time it passed over the balloons. In addition, the balloons sent signals that could be analyzed to obtain the speed and direction of the balloons as they were carried along by the winds. The wind fields themselves could thus be deduced from balloon motions.

Of the balloons flown from Christchurch, 33, sometime in their lifetimes, crossed the Equator into the Northern Hemisphere. The crossings occurred only in two narrow bands of longitude: between 180° and 140° E (from central Australia to the International Dateline) and between 0° and 30° W (over the Atlantic between South America and Africa). TWERLE scientists theorize that a connection between the two hemispheres at the 14-kilometer level is effected through features of the large-scale planetary circulation in the tropics often called "midoceanic troughs"—areas of lower pressure.

TWERLE scientists also discovered that a balloon platform registering pressure, temperature, and altitude can be a powerful and economical tool for studying wave motion in the high atmosphere. Three kinds of wave motion could be detected: a neutral balloon oscillation (the balloon restoring itself to equilibrium density level after a perturbation) with a period of about 4 minutes; a lee-wave oscillation in balloons launched from Christchurch passing downstream of orographic barriers, with a period of 6 to 7.5 minutes; and oscillations with periods between 30 minutes and 1.5 hours that are believed to be the signatures of gravity waves. All three types of waves may originate near the ground from any number of sources (the motion of the oceans, convective circulations) and may be dissipated at the tropopause; conversely, they may be excited at the tropopause and have no association with topography beneath them. A study of energy flux statistics that can be calculated from the balloon motions may help to pinpoint the source.

The balloon platforms were able to "see" extraordinary vertical air motions associated with deep convective circulations in the tropics—in one case a windspeed of about 3 or 4 meters per second in the vertical, a rapid rise even for a deep tropical convective storm. Turbulence statistics on a larger scale also were visible from the clustering patterns of the balloons. In contrast to the expected random drift pattern, the balloons launched from the tropics often appeared to avoid some areas and to cluster thickly in others. The clustering of the balloons over the tropical Atlantic, for example, was a

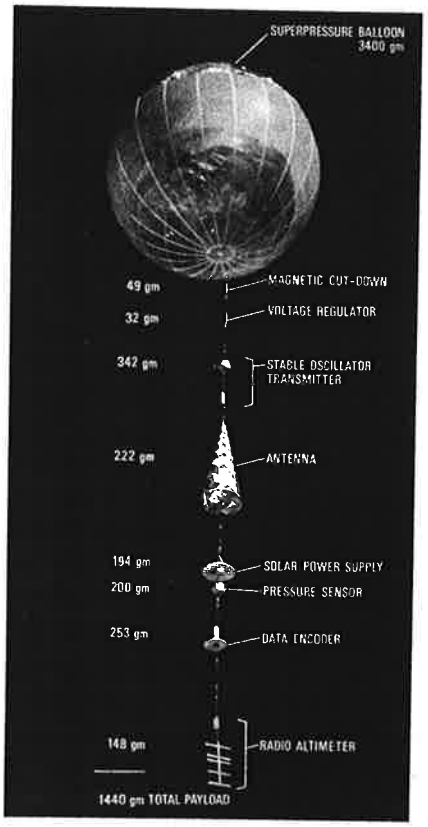
persistent feature indicating that the upper-level winds tend to converge or move inward over this geographical region. The virtual absence of balloons in the vicinity of the monsoonal easterly flow over northern Africa, the Indian Ocean, and Indonesia, which persisted during the period of the experiment, indicated that the winds fanned outward or diverged over these points. Persistent, large-scale areas of mean divergence or convergence of upper-level winds of such a magnitude have not been observed at midlatitudes. Further analysis should reveal how such tropical features are integrated into the general circulation of the Earth.

The experiment will be repeated during the First Global Atmospheric Research Program (GARP) Global Experiment (FGGE), one of the experiments of GARP. The satellite receiver system will be the French ARGOS system aboard TIROS N. NCAR will fly 300 TWERLE-type balloons in the tropics under the support of the National Oceanic and Atmospheric Administration.

Global Atmospheric Research Program

Results of the Global Atmospheric Research Program's (GARP) first experiment, the GARP Atlantic Tropical Experiment (GATE), began to emerge in fiscal year 1976. Data collected during the summer 1974 observational phase of GATE have been edited, validated, and archived and are now available to the scientific community. One data set contains low- and high-level tropical winds derived from satellite cloud information. This is a very important application of meteorological satellite information to the tropics, a data-sparse region.

From a GATE project designed to characterize airborne particles (aerosols) transported from the African Continent over the Atlantic Ocean, a possible anthropogenic impact on weather and perhaps climate was discovered. In semiarid regions bordering deserts, rainfall is highly variable. With development comes increased grazing, ploughing, and cultivation of new land, plus removal of trees. Overgrazing influences aerosol generation, and during dry periods vast reservoirs of dust are transported into the atmosphere by winds. This dust modifies the radiative properties of the atmosphere to a significant degree and may lead to suppressed precipitation. This, in turn, would increase aerosol loading.

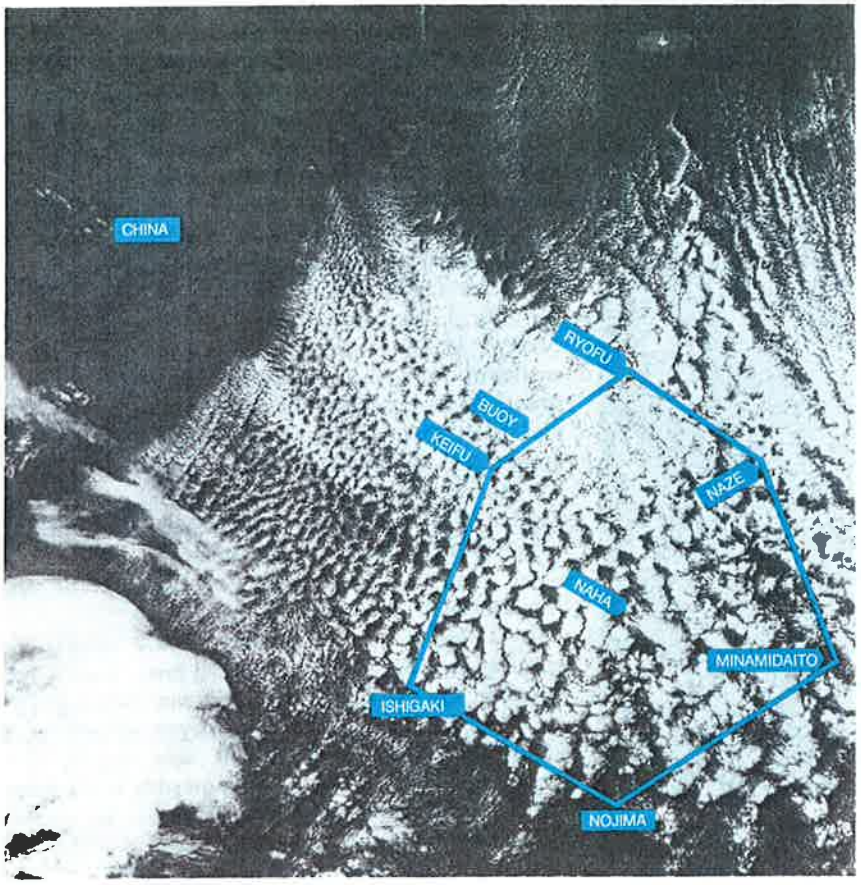


Interhemispheric air exchange. More than 400 of these scientific balloons were flown between May 1975 and January 1976 in an NCAR/NASA/University of Wisconsin study of air circulation 14 kilometers above the tropics. This information is important to understanding how the general circulation of the world's atmosphere determines weather patterns.

Several new and unexpected findings are emerging from the Indian Ocean Experiment (INDEX), a study of the structure of the circulation in the western Indian Ocean. INDEX is a predecessor of a GARP regional experiment, the Monsoon Experiment (MONEX), that will be held during 1978-79. MONEX is one of several experiments embedded within the First GARP Global Experiment (FGGE). The Equatorial Undercurrent (a fast moving, subsurface, eastward flowing current) has been found to be considerably more complex than at first thought. A depth-dependent alternating structure of the undercurrent, which persists to depths of at least 3 to 5 kilometers, suggests that it is not clear exactly what one should identify as the "Equatorial Undercurrent."

In a related INDEX effort, six satellite-tracked drifter buoys released in the equatorial Indian Ocean were caught in a large clockwise gyre whose existence was totally unknown. The gyre or eddy had a mean speed of 70 centimeters per second and maximum speeds in excess of 200 centimeters per second.

Preliminary results of another GARP effort, the Air Mass Transformation Experiment (AMTEX), were discussed by scientists from Japan, Austria, Canada, and the United States at a conference in Tokyo in September 1975. AMTEX was designed to increase understanding of wintertime airmass modification in regions where cold, dry continental air flows over warm ocean water. The region of the warm Kuroshio current in the East China Sea, a strongly preferred region for intense winter storm development, was selected. The physical processes involved are thought to play a similar role in the Gulf Stream region off the southeast coast of the United States where many intense storms are generated. AMTEX results indicate a substantial variation in energy input from the ocean to the lower at-



Stormy weather. Results of a Global Atmospheric Research Program study of the flow of cold, dry continental air over warm water in the East China Sea (the research area is outlined) will help explain how intense winter storms develop. The cloud patterns in this February 16, 1976, satellite photo result from this cold air/warm water interaction; similar processes probably operate in the Gulf Stream off the southeastern United States. (Photo courtesy of E. M. Agee/Purdue University.)

mosphere, depending on the character of the advancing airmass. These findings offer atmospheric modelers an opportunity to account more realistically for energy input into models designed to forecast incipient storms.

Climate Dynamics

Studies by researchers at the Lamont-Doherty Geological Observatory and Brown University of the frequency of past climatic changes as deduced from environmentally sensitive indicators preserved in deep sea cores have provided valuable insight into mechanisms of climatic change. These researchers have shown that the long-term climatic variations in both hemispheres over the past 400,000 years have the same periodicities and constant phase relationship as variations of the Earth's orbital parameters. The indicators of past ocean surface temperature, continental ice volume, and species abundance fluctuate with periods of 100,000 41,000, and 23,000 years, which are the same as the Earth's eccentricity, obliquity, and precession cycles. While both the climatic and astronomical cycles are generally in phase, the 41,000- and 23,000-year climatic cycles systematically lag the obliquity and precession cycles. These studies show demonstrable evidence of some orbital control for climatic change and indicate possible lags in the climatic response given by the Earth to changes in its orbital position.

The relationship between sea surface temperature anomalies and continental climates is becoming clearer as a result of research conducted by John Kutzbach and David Houghton of the University of Wisconsin and climate modelers at the National Center for Atmospheric Research. These researchers have demonstrated that the NCAR General Circulation Model exhibits a well defined response to changes in sea surface temperatures. In model experiments, sea surface temperature anomalies in the North Pacific Ocean produced a wavelike perturbation in the upper air patterns extending downstream over the continental United States, thus supporting an earlier hypothesis of Bjerknes (UCLA) and Namias (Scripps).

With a positive change in sea surface temperature there is an increase of atmosphere temperature extending to mid-troposphere, increased vertical motion, and an upper level increase of pressure coupled with a low level decrease of pressure. Low pressure systems form and/or intensify over such an area. With a negative sea surface temperature change, the response is exactly opposite. These significant findings emphasize the important role of sea surface temperatures in regulating continental climate and form a useful point of departure for continued and further examination and understanding of aspects of actual mid-latitude atmosphere-ocean interaction.

National Center for Atmospheric Research

The National Center for Atmospheric Research (NCAR), located in Boulder, Colo., conducts, in cooperation with universities and other institutions, large atmospheric research programs of national and international importance. NCAR also develops and provides major research facilities in support of atmospheric research programs. NCAR is operated by the University Corporation for Atmospheric Research (UCAR), a nonprofit consortium of 42 U.S. and 2 Canadian universities, under contract with NSF.

This past year NCAR scientists completed the first direct comparison of forecasts produced by several large-scale numerical weather prediction models. Some of the results confirmed expectations. For example, all the models display some of the same characteristic errors; they forecast phase speeds for waves in the atmosphere that are slower than the actual atmospheric motions; they predict weaker amplitudes than those that are observed; and they describe the development and decay cycle of disturbances poorly.

Other conclusions were unexpected. Even though the three models were developed independently and employed distinct methods of calculation, they produced forecasts that were surprisingly similar. Moreover, the scientists had expected that the largest forecast errors might occur over geographic areas with the smallest amount of observed data (e.g., over oceans), but the actual forecasts showed no such simple geographic dependence, even in the first 24 hours. The first quantitative evaluation of different models provides some directions for future research. All the models need to be improved to reduce their common errors.

Results from the battery of solar telescopes operated by astronauts aboard Skylab have contributed greatly to the understanding of a number of problems in solar physics. NCAR's white-light coronagraph was one of six telescopes flown on the spacecraft. Using Skylab data, solar scientists are clarifying relationships between events in the Sun's tenuous outer atmosphere—the corona—and the structure and dynamics of the interplanetary medium. The most general result from Skylab is the changed scientific picture of the corona: what was thought to be always a relatively quiescent outer atmosphere proved at the time of Skylab (near a minimum in the solar activity cycle) to be a highly dynamic structured region.

As a national center, NCAR develops and operates a variety of special research facilities. During the past year, NCAR's fleet of instrumented aircraft participated in a variety of experiments, studying hail over northeastern Colorado, measuring hydroxyl radicals in the stratosphere, and sampling the plume of an Alaskan volcano.

Another important NCAR accomplishment in fiscal year 1976 was the selection of a "fifth-generation" computer, to be delivered in 1977. The new computer and associated hardware will enable scientists to process data from such enormous efforts as the First GARP Global Experiment, slated to take place in 1978-79. This computer and its peripheral equipment will make NCAR's Computing Facility the world's largest and most versatile devoted to atmospheric research.

NCAR successfully deployed a new weather observing and reporting system, the Portable Automated Mesonet (PAM) in fiscal year 1976. PAM samples data at the same time at each of 15 field network stations, averages the data locally, and then transmits it via a telemetry link to a base station so scientists can "watch" surface weather patterns across an entire network in real time. PAM thus represents a technological advance over a whole previous generation of instrumentation.

Earth Sciences

During the past decade, geology (or earth sciences) has undergone a major revolution, the second in the history of this science. Commonly referred to by terms such as "seafloor spreading" and "plate tectonics" or "global tectonics," it has provided us for the first time with a unifying concept of global structure and composition, a model of how the major features of the Earth's surface have been formed and changed, and the first keys to the basic driving forces of a dynamic and ever-changing planet. The concept has enormous promise in explaining the origin and locations of earthquakes, volcanoes, and the processes involved in faulting and mountain building, with practical applications in natural disasters and the formation of deposits of minerals and fossil fuels.

It would be difficult to overstate the success of the plate tectonics model in bringing together the diverse specialties that constitute the earth sciences. Ten years ago no one would reasonably have predicted that paleontologists, geomagnetists, marine geologists, petrologists, structural geologists, and seismologists would be working in concert to supply crucial tests for a concept comparable to that of the Bohr atom in simplicity, elegance, and potential to explain a wide range of diverse

observations. Yet this has indeed happened, and the result has been a revitalization of the geological sciences comparable to that which swept physics at the beginning of the century.

But the new theory is still in its childhood. Although most major lines of evidence reinforce the model, there are some phenomena that appear in part or in *toto* to be inconsistent with the plate tectonics model, and there are others that appear at this stage to be unrelated. Therefore this attractive and promising theory needs very critical testing and evaluation. Its implications and its *limitations* in explaining the Earth need thorough exploration.

Thus a good deal of the research supported by the earth sciences program is focused directly on the elaboration and testing of the plate tectonics model. And most of these projects are subsumed under the U.S. part of the International Geodynamics Project, an effort involving some 45 nations. Many are also closely related to fundamental earthquake studies.

Nearly as exciting as geodynamics *per se* is the focus and new significance that plate tectonics has given to much of the "old-line" geologic research. Thus, projects that study the granites of a mountain belt—fine research but of local significance 25 years ago—are now pieces in the whole global picture of subduction zones and plate boundaries. And the study of fluid inclusions in crystals tells us not only the temperature at which an ore deposit formed but also something about the temperature and physical-chemical conditions of the descending slab of a crustal plate.

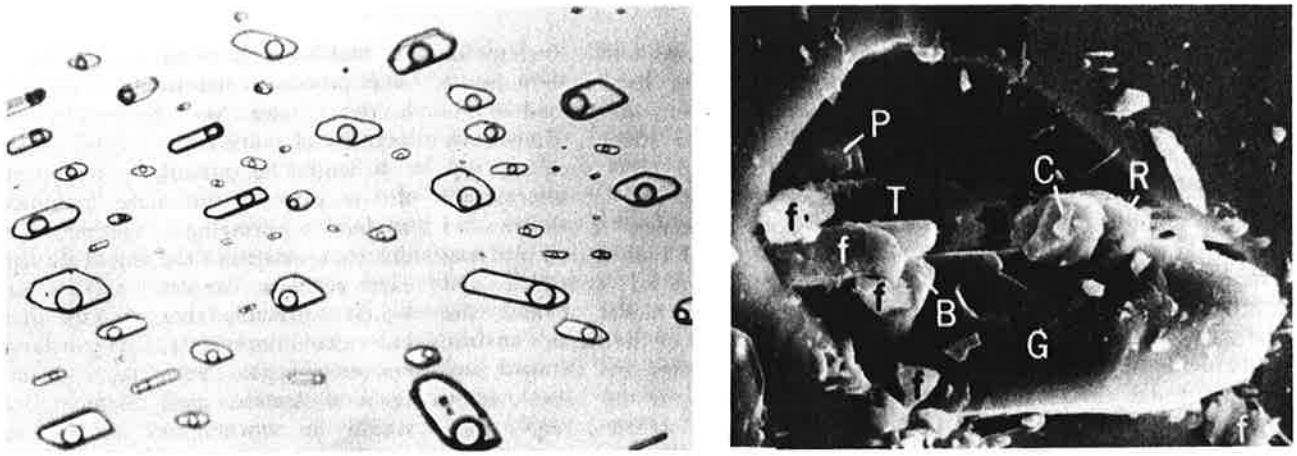
A major and special source of current geological data is the Deep Sea Drilling Project. Having made major contributions both to the plate tectonics model and to general geologic knowledge, the project entered its fourth or formal International Phase in November 1975. More than just a mere extension of the early reconnaissance drilling, this new phase focuses more on problems and will involve both deeper penetration and more continuous coring. The results should add greatly to our understanding of the history of ocean basins and the evolution of the outer crust.

Fluid Inclusions

Many ore deposits, especially the metal sulfides, form by the precipitation and growth of minerals from hot, saline water solutions that move through rocks. Small droplets of these fluids are commonly trapped by growing crystals as microscopic fluid inclusions. The past decade has seen renewed and increased interest in the study of these fluid inclusions because they are a powerful tool in reconstructing the physical-chemical conditions of formation of ore deposits.

One of the targets of the studies is temperature. The coefficient of thermal expansion of the fluid is more than that of the enclosing crystal, and vacuoles (small cavities) are formed in the inclusions when the deposit cools. But the process is reversible, so that when we observe the temperature at which the vacuoles disappear on heating, we derive an estimate of the temperature of the solution at the time of entrapment. The salinity of these solutions has also been estimated in an analogous manner by observing freezing point depression.

Of even greater interest are the specific compositions of the fluid inclusions and the minerals that form in the cavities by precipitation on cooling of the deposit. Attempts at more precise determination of fluid



Mineral history. New methods for studying microscopic pockets of fluid trapped in larger crystals now permit the reconstruction of details of how hydrothermal ore deposits were formed. At the left, small bubbles in fluid inclusions of a fluorite crystal can reveal the temperature of the solution when it was entrapped. At the right, a scanning electron micrograph of an opened inclusion shows different minerals that have crystallized from the entrapped fluid.

composition are now being made using laser-excited Raman spectroscopy for *in situ* partial chemical analyses and by opening and analyzing the volatilized constituents of individual inclusions by laser microprobe methods. These methods are still in the development stage.

A significant advance in identifying the minerals in the cavities has been made by geochemists at the University of Michigan. This group, led by William C. Kelly, includes F. W. Metzger, B. E. Nesbitt, and E. J. Essene. Previous attempts at identification of the inclusions involved optical and transmission electron microscopy, but neither method was precise because of interference by the enclosing crystal. The Michigan group has now developed a technique of definitively determining the composition of the inclusions by using a combination of scanning electron microscopy and energy dispersive analysis of the X-ray spectrum excited by the electron beam. The analysis is made on crystals in which the inclusions have been exposed by fracturing.

Using this method they have identified a complex assemblage of inclusion minerals in fluorite crystals that come from the famous gold-telluride deposits of the Colorado Front Range. Preliminary identifications have also been made of the assemblages present in quartz crystals from gold-bearing veins of the Oriental Mine at Alleghany, Calif., and from calcite crystals in the carbonatite rocks at Magnet Cove, Ark. The development of this technique is of prime importance in that the inclusion mineral assemblages reflect the chemical composition, total salinity, and cooling history of these deposits. The fact that individual inclusions can be analyzed makes it possible to trace the history of crystallization of ore deposits; it should, therefore, lead to substantial new knowledge about their modes of formation.

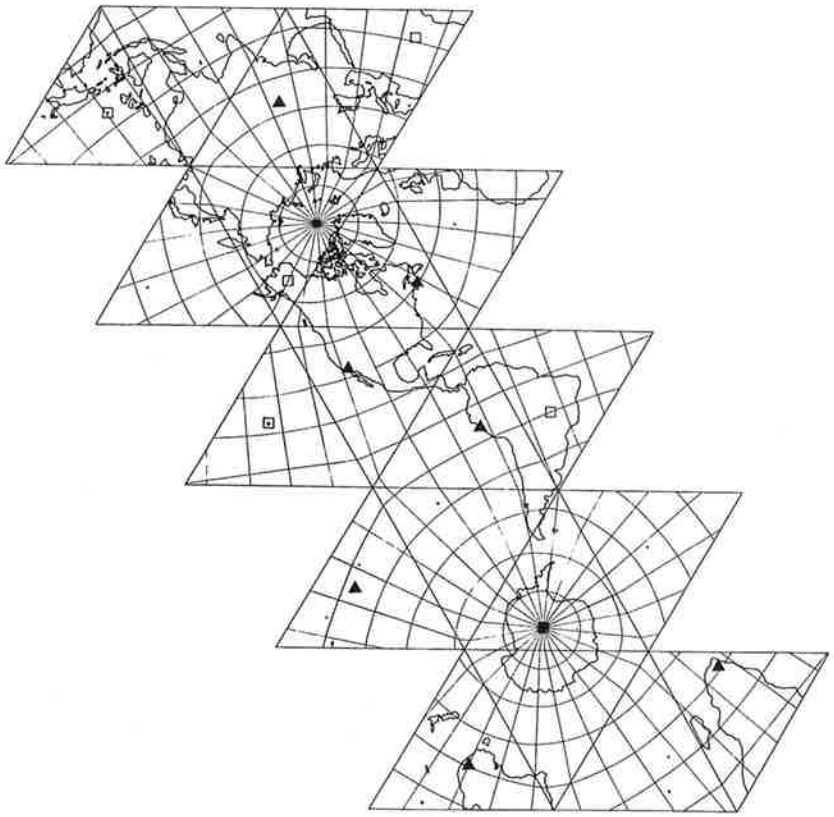
A Very Long Period Seismic Array

An area of geophysical research of great interest and potential practical importance is the basic study of earthquakes. Even though a lot of hard work lies ahead, enough progress has been made since the 1964 Good Friday quake in Alaska to provide encouragement that such earthquakes can be predicted.

One important element in earthquake research is the measurement of crustal stress on a global scale, because there is increasing reason to believe that local earthquake occurrences are related to such global behavior. Thus, increased knowledge about stresses in the Earth on a worldwide basis will aid research directed at earthquake prediction on the more local level.

To this end, a network of modified La-Coste Romberg vertical accelerometers is currently being installed by University of California, San Diego, scientists at selected sites around the world. The instruments are the most sensitive ever developed, and the network, which will optimally consist of approximately 20 stations, will provide a unique set of high-quality, very long period digital data.

Stations are presently installed at Pinon Flat, Calif.; Canberra, Australia; Nana, Peru; Sutherland, South Africa; Halifax, Nova Scotia;



Global network for long period seismology. This network of seismic instruments will provide better data for the study of the free oscillations of the Earth, the distribution of global stress patterns, solid Earth tides, and earthquake source mechanisms. Seven stations are now operating (colored triangles); projected sites are shown by open squares.

Garm, U.S.S.R.; and Rarotonga, Cook Islands. The station at Garm, installed in September 1976, is the first and only permanent western seismograph station in the Soviet Union. Other stations definitely to be installed include Brazilia, Hawaii, and Alaska. In the case of foreign stations, the United States provides the equipment and such maintenance as is necessary, while the foreign nation provides all operational costs as well as the critical geographical position. Success of the network depends on international scientific cooperation. Data are available to all interested scientists through the Environmental Data Center of NOAA.

As of September 1976, seven stations were operational. Although most of these have not been running long enough for multiple record analysis (i.e., to use them as a network), significant scientific results have already been obtained from the analysis of single station data. For example, the processing of several weeks' records from Nana, Peru, show clearly the 8-hourly tide at the 1 to 2 percent level, something never before seen. From such data, it will be possible to determine whether the elastic properties of the Earth vary as a function of tidal period—important information for studies of the Earth's core. In the seismic band, a new method to selectively amplify the long-lasting vibration modes (high Q) will aid other studies of deep earth structures. From the records of the recent Guatemala earthquake, for example, Q was determined for many of the fundamental modes and some overtones to an accuracy of 3 to 4 percent, far greater accuracy than ever before achieved.

With the completion of the sixth and seventh stations, it is now possible to look at source mechanisms of large earthquakes in the long period band. The records from six stations should enable the determination of the pattern of stress release for time intervals of 1 minute to 1 hour and should permit us to know what useful precursors, if any, can be observed for large earthquakes.

Ocean Sediment Coring Program

For the past 8 years, the Deep Sea Drilling Project, a part of the NSF Ocean Sediment Coring Program, has been drilling and coring in the sediments and upper basement rocks of the world's ocean basins to determine their composition, structure, and geologic history. The project is managed for the Foundation by the University of California, with the Scripps Institution of Oceanography of the university responsible for accomplishing the project's scientific objectives. The University of California subcontracts with Global Marine, Inc. (GMI) to perform the actual drilling and coring operations using GMI's ship *Glomar Challenger.*

Early in fiscal year 1976 the project completed its third phase of operations. By the end of this phase 573 holes at 392 different sites were

Aboard *GLOMAR CHALLENGER.* Philip Rabinowitz of Lamont-Doherty Geological Observatory, a co-chief scientist on Leg 45 of the Deep Sea Drilling Project, inspects a downhole hydrophone used to measure sonic characteristics of rocks below the ocean floor. DSDP research in 1976 resulted in new findings about young crustal material and about events associated with the splitting of North America from Europe and Africa.

drilled in all the major deep water ocean basins and seas of the world. A total of 493 shipboard scientists participated in the first three phases of ocean drilling; 196 persons have served as scientific advisers to the project. A total of 54,194 separate samples were distributed to 528 U.S. and foreign scientists from academic institutions, industry, and government agencies.

The fourth phase of ocean drilling, the International Phase of Ocean Drilling (IPOD), is being conducted with increased international support. In January 1974 the Soviet Union signed a Memorandum of Understanding with NSF, agreeing to contribute $1.0 million per year to the project for 5 years. Since the beginning of fiscal year 1976, agreements to contribute $1.0 million per year to IPOD were signed by Japan, the United Kingdom, France, and the Federal Republic of Germany.

Drilling operations during fiscal year 1976 concentrated on two main objectives: (1) to drill as deeply into the basaltic crust of the ocean as possible within a limited time frame to determine its origin and evolution, and (2) to penetrate the thick wedge of sediments along the Atlantic Ocean margins to better understand the paleoenvironmental changes that took place when North America split from Europe and Africa.

Legs 45 and 46 were devoted to drilling into the basaltic rocks approximately 90 miles from each side of the Mid-Atlantic Ridge at 22° N latitude. While a great deal was learned about young crustal material near a ridge axis when fractured basalt and layers of basaltic sand were penetrated, drilling was difficult and maximum penetration was limited to 664 meters. The detection of several magnetic reversals in just a few hundred feet of basalt was a surprise to most scientists. The first deep-sea well-logging program in crystalline rocks was successfully carried out after drilling operations ceased.

Legs 44, 47, and 48 were important in determining the history of the early opening of the Atlantic Ocean. Huge submarine mudflow and avalanche deposits were discovered on both sides of the Atlantic. Chaotic pebbles, lumps of mud, and crinkled layers of ooze were carried from the relatively shallow shelves to deep water, probably carving submarine canyons across the slope as they went. Large quantities of organic matter quickly buried by this process await the right geological conditions for conversion into oil and gas.

Evidence indicates that when North America first split from Europe and Africa there was a rapid collapse of the continental margin. Off the United States there were Bahama-type tidal flats that rapidly subsided more than 2,700 meters and, in the Bay of Biscay, swamps fringed with coral reefs sank 1,200 meters below sea level. Strong submarine currents along the continental margin at one place swept away a blanket of sediments over 3 kilometers thick. At other times, stagnant conditions developed, resulting in the accumulation of black, organic-rich sediments. Clues to help date the origin of the Sahara Desert and evidence for cold currents that may have changed the Atlantic Ocean's climate help us better understand the paleoenvironment of the Atlantic region.

Glomar Challenger will finish the present Atlantic Ocean drilling schedule by February 1977. At that time, it will embark on a 2-year Pacific Ocean program.

Ocean Sciences

The overall objective of NSF's programs in the ocean sciences is to improve our understanding of the nature of the ocean, its influence on our activities, and our own impact on the marine environment. This is accomplished through three major programs: one basic research program to support projects of individual scientists at the oceanographic institutions, a second to support a limited number of large, managed projects, and a third program to provide for the acquisition and operating costs of the ships and other oceanographic facilities needed to carry out these research programs.

Support for individual research projects provided more than 300 grants in fiscal year 1976 to individual scientists for developing fundamental knowledge about the oceans, their contents, and the sea floor. Investigations concentrate on physical oceanography, marine chemistry, submarine geology and geophysics, and biological oceanography.

The International Decade of Ocean Exploration supports large-scale, multidisciplinary, international projects focused on the role of the oceans in climate, food production, pollution, energy, and natural resources, with considerable participation by many nations around the world. These efforts are incorporated into four programs—environmental forecasting, environmental quality, seabed assessment, and living resources.

Oceanographic facilities and support contributes directly to these oceanographic research efforts by providing support for 30 research ships and a number of specialized facilities; these are scheduled on a shared-use basis. Based on its programs for review and evaluation of academic fleet performance and material condition, NSF supports a

continuing effort to upgrade the facilities necessary to sustain a viable oceanographic research effort at the Nation's universities.

Cycling of Dissolved Organic Matter in the Sea

Energy flow in the ocean has been studied for many years from the perspective of the classical model of a food chain—diatoms through copepods and krill to fish and whales. However, recent studies by a number of researchers have revealed that the major portion of the ocean's available energy may be flowing through a food web comprised of dissolved organic matter, nonliving organic particles, and those microorganisms such as bacteria that can consume this organic matter directly. Little is known about the nature and concentration of either the dissolved material or the consumer organisms.

John Sieburth of the University of Rhode Island has directed his studies towards these problems for several years, and on a recent project he focused his attention on the thin layer of water at the sea surface, a zone particularly likely to be affected by pollutants such as petroleum hydrocarbons. He found that this microlayer, and particularly the ultrathin "skin" at the water surface, is rich in dissolved organic carbon, apparently of phytoplankton origin. Incubations using this water demonstrated that it supports active microbial populations in concentrations approaching those of laboratory cultures.

Primary consumers. Food chain interactions in the ocean's very thin surface layer may be far more important to marine life than previously thought. Typical inhabitants of this microlayer are shown in this electron micrograph of the surface of a blue copepod that has been colonized by a suctorian protozoan. The protozoan uses its combination of outer and inner feeding tentacles to capture and ingest bacteria that live in the surface waters. (Photo by John Sieburth/University of Rhode Island.)

Sieburth hypothesizes that the upward nocturnal migration of grazing zooplankton may serve to transport and subsequently release these dissolved materials into the surface waters. Microscopic observations of blue-pigmented copepods floating on the water surface provided an interesting illustration of this food web dependent on dissolved organics. A large percentage of the copepods were infested with a suctorian (stalked protozoan). Microscopic sections through the suctorians indicated that they are consuming the microorganisms thriving in these rich surface waters. The suctorians and their copepod hosts are, in turn, a source of food for larger invertebrates and larval fish.

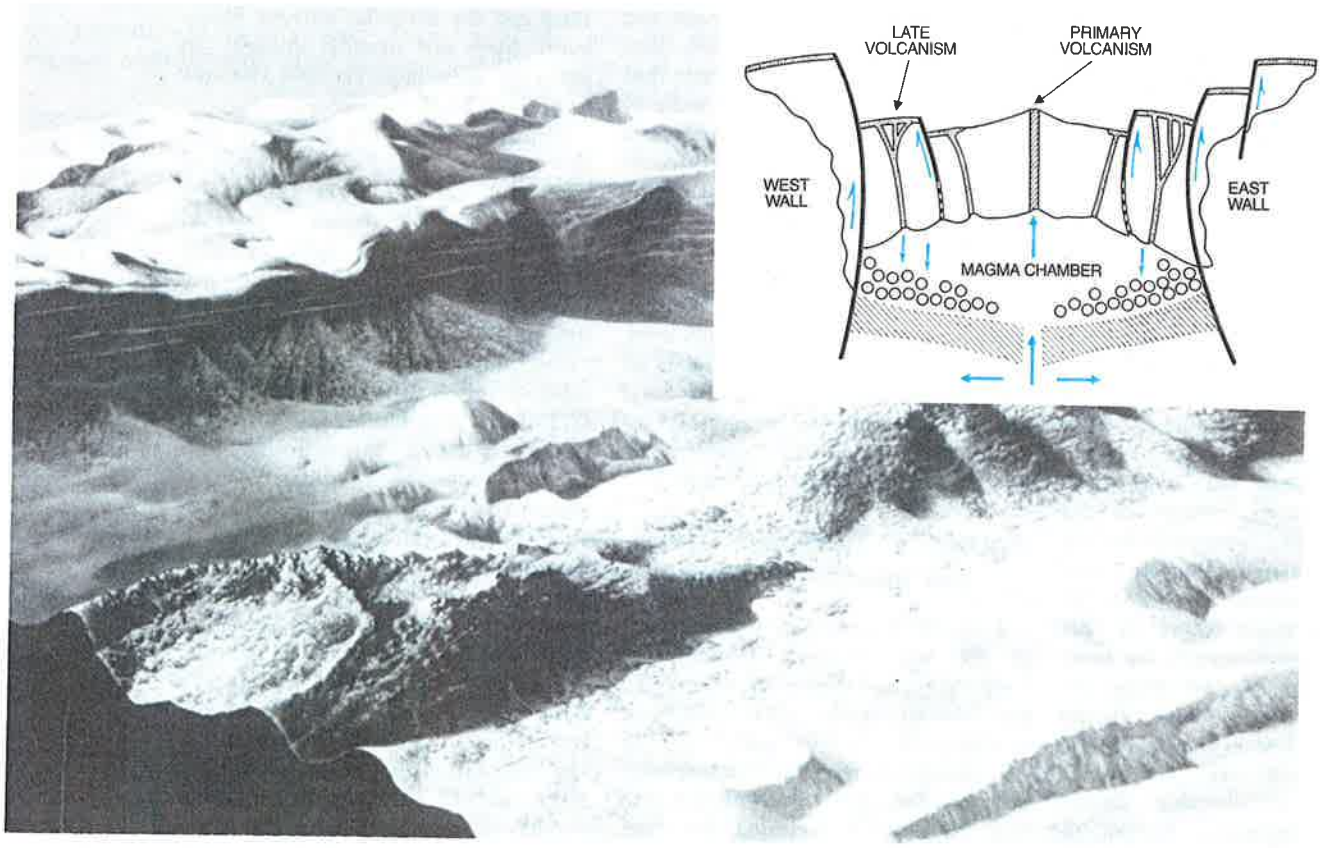
In further studies in waters below the surface microlayers, Sieburth employed a diffusion culture apparatus to measure the *in situ* growth rates of these microorganisms. The diffusion culture system is a chamber divided by a membrane. The membrane acts to cage a population of microorganisms on one side of the chamber while exposing them to

natural fluxes of dissolved organics that actively diffuse through the pores in the membrane. In contrast to previous experiments in closed bottles, this chamber allowed the microbial populations to achieve maximal growth rates reflecting the dynamics of the supply of dissolved material in the seawater. The resulting growth rates were two orders of magnitude higher than generally reported for the open sea. This experiment suggests that a large amount of organic matter is in a dynamic state, rapidly cycled by microorganisms. In addition, the resulting bacterial biomass indicates that the open oceans are more productive than was previously thought. This finding helps explain the longstanding discrepancy between our estimates of the standing stocks of zooplankton, fish and whales, and the insufficient phytoplankton production presumed to support these populations. While this work requires additional substantiation, it provides an important new perspective in our efforts to determine the processes that maintain the long-term equilibrium of life in the sea.

Project FAMOUS: Sea-Floor Growth

Understanding of the structure of the oceanic crust has rapidly advanced in recent years as a result of the development of the theory of global plate tectonics. Stated very briefly, the Earth's outer shell is made up of a small number of large semi-rigid plates that move relative to one another. New oceanic crust is formed at the crest of midocean ridges and then migrates or spreads laterally from the crest at a rate of the order of several centimeters per year. Ultimately, it sinks into the Earth's mantle at the oceanic trenches.

Project FAMOUS, an abbreviation for French-American Mid-Ocean Undersea Studies, concentrated on examining the tectonic and geochemical processes active at midocean ridge crests. A segment of the inner rift valley of the Mid-Atlantic ridge was investigated in detail from the submersible *Alvin*. The chief diving



Seams of the Earth. A model and cross-sectional diagram, reflecting observations made with the submersible *ALVIN* along the Mid-Atlantic ridge, show the raised central volcanic area, the lower collapsed zones on either side, and the uplifted area still further from the spreading center.

scientists, R. D. Ballard, J. R. Heirtzler, and W. B. Bryan of Woods Hole Oceanographic Institution, T. H. van Andel of Oregon State University, and J. G. Moore of the U.S. Geological Survey, made 15 traverses across the floor of the rift and up the flanking valley walls to the first major fault scarps. The data from *Alvin* were broadened with information collected in the area with more conventional techniques, leading to a complete geological interpretation of the study area.

The geologic model shows that the central part of the rift is a product of extensive volcanic activity and active faulting. Small volcanoes are built up along the spreading axis; shortly after formation, the volcanic structure is modified by vertical collapse, which leads to a reduction in the bottom relief. This process is reversed in the outer parts of the rift valley as uplift begins. Here the tensional nature of the stresses changes to vertical shear as the volcanic blocks are incorporated into the valley walls and elevated. During the various stages of uplift, terraces are formed and some of the original volcanoes can be recognized. Mineralogical and geochemical analyses of volcanic rock samples recovered by the submersible, coupled with the examination of volcanic flow features, show that some of the lava flows come from secondary fissures within the rift valley. The source regions for the flows—magma chambers—are shallow and show considerable variation in composition. The range of volcanic rock types found in this small area is approximately the same as the variations found along the entire length of the Mid-Atlantic ridge. Thus, it appears that magmatic processes such as fractional crystallization or variable partial melting are important factors in controlling composition of individual groups of lava flows. Magma batches arriving at the magma chamber do not completely mix with the magma already present, producing a zonation within the chamber which is enhanced by fractional crystallization.

Age sequences for the lava flows show, in general, an orderly progression of young to older rocks going from the axis to the valley walls. A few anomalously old rocks are found in the axial depression. The most striking anomaly, however, is a scatter of very young rocks across the entire width of the valley floor. This suggests that a shallow magma reservoir exists with free communication across the width of the valley floor. Episodes of major volcano building along the axis apparently alternate with reduced activity along the axis and more widespread activity from the secondary fissures.

Results from Project FAMOUS are being incorporated into kinematic and dynamic models of the sea-floor spreading process. It is apparent that on the spatial and temporal scale of this study, the processes in midocean rift systems are not continuous. Additional laboratory analyses of the rock samples should define the shape of the magma reservoirs and the sequence of events with much greater precision. The detailed geologic study of the FAMOUS area, coupled with geophysical models of the deeper crustal structure and volcanic emplacement processes, are generating improved geodynamic models for this seafloor growth.

Equatorial Tides, Sea Levels, and Internal Motions

A recent discovery by Carl Wunsch of the Massachusetts Institute of Technology has shown that it may be possible to study very long-term variations in oceanic water movements by the proper interpretation of data on tides—phenomena that have been recorded for centuries.

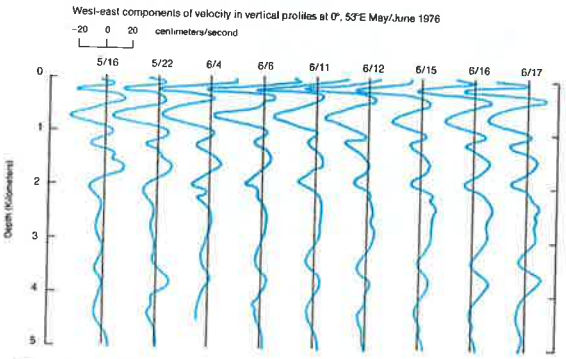
Tides can, in general, be thought of as periodic changes in sea level produced by the gravitational pull of the Moon and Sun. Numerical models have been very successful in predicting tidal heights over very small geographic areas. However, in some regions of the ocean, particularly near the Equator, variations in the sea level records cannot be explained simply as tides. For example, some 20 years ago Gordon Groves, now with the University of Hawaii, pointed out a 4-day oscillation in the tropical Pacific. Some scientists speculated that this and other unexplained variations might be due to internal motions in the sea—large disturbances of the interior of the ocean due to its large density variations. These internal motions can be generated by interactions with the atmospheric wind and pressure fields, as well as by the interactions between tides and the irregular bottom. However, they are usually thought to generate only imperceptible changes in surface level.

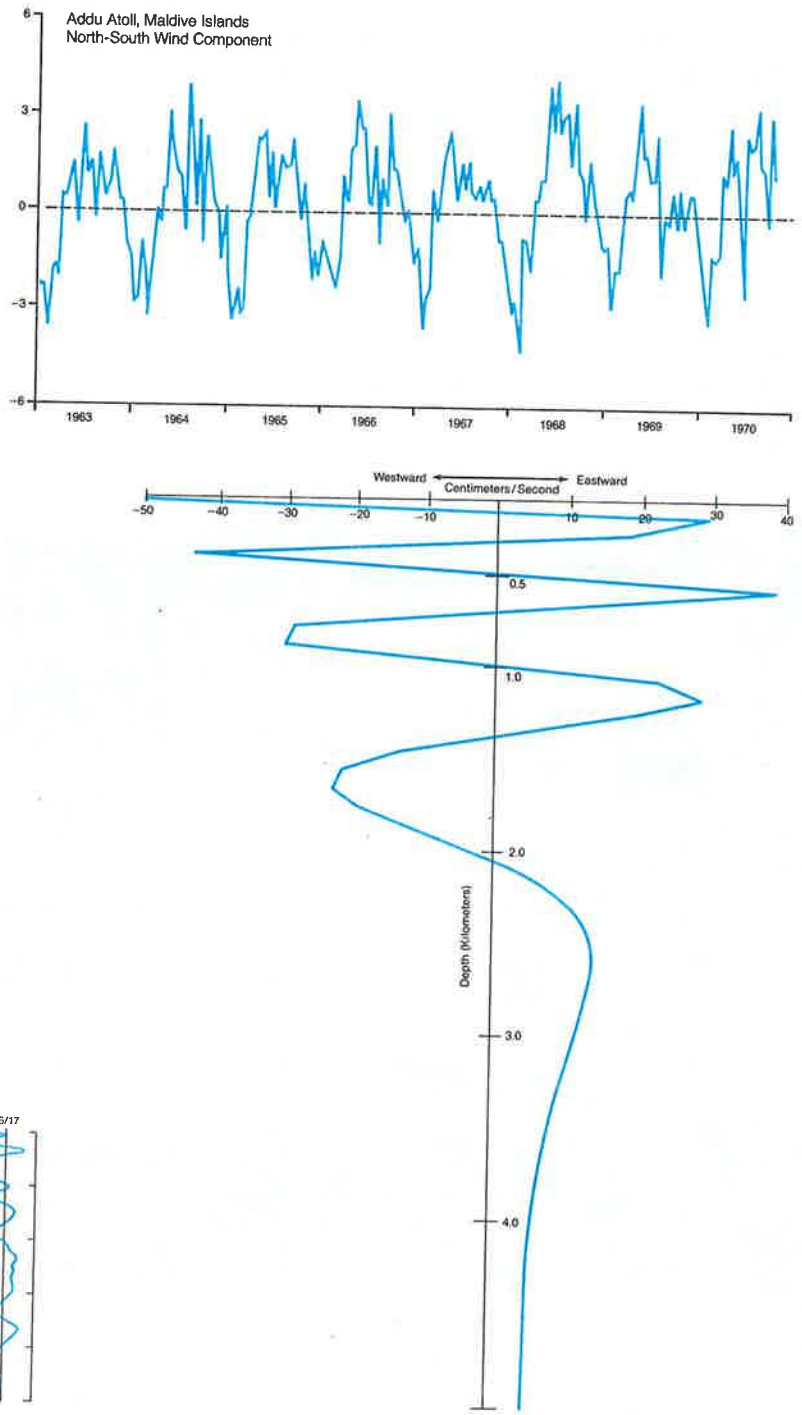
Wunsch's surprising discovery was that small but significant portions of sea level variations *are* caused by atmospherically driven internal motions and not entirely by tidal motions. In fact, if tide records are properly interpreted, several density-dependent internal motions can be "seen" superimposed on the surface tides. Wunsch and a colleague, A.E. Gill, from the University of Cambridge, showed theoretically that several types of nontidal internal motion can occur near the Equator, that they are caused by variations in atmospheric wind conditions, and that they can explain some of the unexpected components observed in equatorial Pacific tide gauge records.

To pursue this finding, tide gauges have been placed on islands of the Indian Ocean as a method of studying the response of that ocean to the very large annual changes in the wind conditions associated with the monsoon. Preliminary analysis of these records and of historical data indicates that the monsoon can be treated as a periodic disturbance with

an annual, or possibly semiannual period. An application by Wunsch of a model used by meteorologists shows that this periodic forcing can result in a layered motion at the Equator, with the water at alternating levels moving eastward or westward. The layers themselves move upward and downward very slowly, and on the basis of short-term current measurements look like the usual equatorial currents and undercurrents. Recent measurements of the vertical velocity structure by James Luyten of the Woods Hole Oceanographic Institution tend to agree with Wunsch's analysis.

In summary, equatorial ocean circulation is a complicated air-sea interaction problem with long time scales and with a variety of spatial scales. Very long-term moorings (possibly for several years) of pressure and current sensors are needed to observe these motions. Because the ocean and atmosphere have similar time scales in these equatorial regions, it is here that one is likely to make the most immediate progress in understanding oceanic motions forced by the atmosphere. There is some hope that this will eventually lead to an understanding of the effects of the ocean on the atmosphere, which is critical to our understanding of climate.



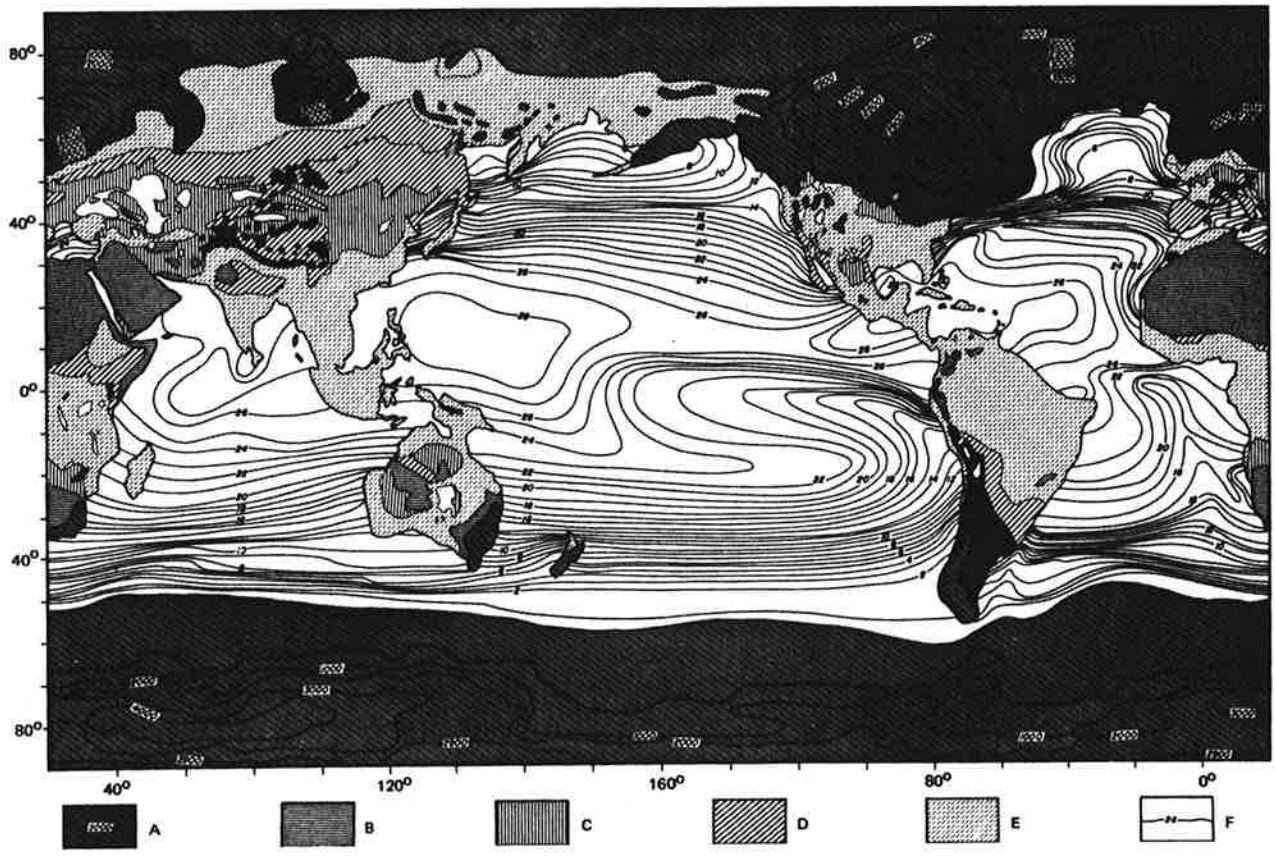


Equatorial tides. An 8-year record (top) of the north-south components of wind at the Maldive Islands, very near the Equator in the Indian Ocean, shows the periodic changes associated with the monsoon. Carl Wunsch of MIT used these annual cycles and a meteorological model to calculate the expected effects on ocean water movement below the surface (right), a calculation that agrees well with actual measurements (left) made 1,000 miles west of the Maldives by James Luyten of Woods Hole Oceanographic Institution. These findings explain how certain tidal variations and parts of the Equatorial Undercurrent system are actually a result of ocean/atmosphere interactions.

International Decade of Ocean Exploration

The Controlled Ecosystem Pollution Experiment (CEPEX), supported by IDOE's environmental quality program, uses large plastic enclosures suspended in the waters of Saanich Inlet, Vancouver Island, British Columbia, to assess the long-term, low-level effects of pollutants on communities of marine organisms captured in these cylinders. In fiscal year 1976, CEPEX scientists from Canada, the United States, and the United Kingdom found indications that copper, mercury, and hydrocarbons have similar effects on organisms occupying the lower levels of the marine food chain. Specifically, bacteria show an initial decrease in population when exposed to these pollutants, followed by a population increase. Researchers also observed that bacteria built a tolerance to the metals used in the experiment, and that this tolerance transferred to other metals as well. For example, bacteria that became tolerant to copper also became tolerant to mercury. In addition, they found that species of phytoplankton become affected in the same order regardless of the pollutant, whether copper, mercury, or petroleum. The loss of those species is reflected in the loss of the zooplankton that feed on them. Thus, the effect on this population becomes predictable with fairly good precision, regardless of the pollutant.

In the environmental forecasting program, scientists in the North Pacific Experiment (NORPAX) have found that temperature abnormalities previously found at the sea surface actually penetrated into the upper layer of the ocean. To study the evolution of these heat anomalies in



CLIMAP. Based on studies of fossils in deep sea sediment cores, this map represents the global environment 18,000 years ago during the most recent ice age. The darkest shade, A, with an albedo (or reflectivity of sunlight) greater than 40 percent, is snow and ice, with the contour lines representing elevation of the ice sheet above sea level in meters. B, an albedo between 30 and 39 percent, is sandy desert, patchy snow, and snow-covered dense coniferous forest. C, an albedo between 25 and 29 percent, is loess, steppes, and semi-desert. D, albedo between 20 and 24 percent, is savanna and dry grassland. E, albedo below 20 percent, is forested and thickly vegetated land. F, with albedo less than 10 percent, is ice-free ocean and lake with sea-surface temperatures shown in degrees Celsius. Continental outlines (note the ice-free land connection between Asia and North America) represent a sea level lowering of 85 meters.

the North Central Pacific Ocean and their relationship to the overlying atmosphere, NORPAX has a continuing measurement program using ships and aircraft of opportunity. NORPAX scientists have also made long-term forecasts of weather as part of their research. Recently, they accurately predicted low rainfall over the midwest during the summer of 1976 and the development of El Niño conditions in the Eastern Tropical Pacific earlier that same year.

Analysis of fossils in deep sea sediment cores has enabled scientists in the CLIMAP (Climate: Long-range Investigation, Mapping and Prediction) Project to describe the main global environmental features 18,000 years ago. Thick ice sheets stretched as far south as New York; sea surface waters were cooler by an average of 2.3° C; sea level was lower by nearly 300 feet; and the Gulf Stream was located far to the south of its present path, running almost west to east, in contrast to the more northerly pattern that it now follows. As also reported in the Climate Dynamics section of this report, CLIMAP scientists have used this data to demonstrate that changes in the Earth's solar orbit are the main cause of global climate changes. These changes seem to occur in cycles of about 23,000, 41,000, and 100,000 years. This data also indicated that climate changes in the Southern Hemisphere occur about 3,000 years before similar changes occur in the Northern Hemisphere.

Scientists from Oregon State University and the Hawaii Institute of Geophysics have continued to analyze the origins of metal-rich sediments in the eastern equatorial Pacific as part of the seabed assessment program. Variations in these sediments appear to be associated with the kind of ocean environment in which they occur. For example, near the crest of the East Pacific Rise, seawater flows through the new sea floor, removes minerals from the new oceanic crust, and deposits them as "hydrothermal" sediments on the sea floor. The northern portion of the East Pacific Rise lies under the zone of high biological productivity of the equatorial Pacific surface waters. Here, barium and zinc are supplied by the shells of surface-dwelling organisms that accumulate on the sea floor. Away from the rise crest, aluminum, silica, and to a less extent, iron and zinc, are supplied by land debris carried away from South America by deep ocean currents. In some areas nickel, barium, copper, and zinc are derived directly from seawater along with the hydrothermal sediments, as well as through alteration of surface sediments.

Along the Galapagos Spreading Center, northeast of the Galapagos Islands, scientists from Oregon State, Stanford, the Scripps Institution of Oceanography, the Massachusetts Institute of Technology, and the Woods Hole Oceanographic Institution are examining the hydrothermal circulation process that leads to the production of metal-rich sediments where new ocean floor is formed. By making sea-floor heat flow and bottom water temperature measurements, these scientists have been able to identify several areas where this hydrothermal circulation is presently taking place. The research submersible *Alvin* will be used during the coming year for sampling of this discharging water. Until now the temperature and composition of this water have been inferred either from laboratory studies of basalt-seawater interaction or statistically by chemical analyses of large numbers of sediment samples. The use of *Alvin* will allow this water to be sampled directly.

As a result of five international field experiments on different coastal upwelling ecosystems, scientists in the living resources program have now shown that fairly small differences in wind, the shape of the sea floor, density and stability fields in the water, and circulation have important effects on the ecosystems. It also appears that large changes in density of undercurrents have a large impact. In fact, these changes may be responsible for the collapse of biological productivity observed during the 1976 El Niño. Scientists are now planning the Joint-II experiment, the most intensive study yet attempted of the rich Peruvian upwelling system.

Research has also continued in the seagrass ecosystem study, which deals with the biological and environmental processes affecting the growth, reproduction, and distribution of rooted marine grasses. These grasses are important as a nursery for fisheries and as a potential receiver of pollutants released into the marine environment.

Oceanographic Facilities and Support

The "academic fleet" consists of approximately 30 major oceangoing and coastal research ships operated by academic laboratories to carry out federally supported research projects. Ship-operating and ship-using institutions have joined in a voluntary association called UNOLS—the University-National Oceanographic Laboratory System—to improve the utilization and effectiveness of the fleet and ensure that ship time is shared equitably.

Capabilities of the fleet have been greatly enhanced during 1976 by the replacement of three converted ships of World War II vintage with the three new *Oceanus* class ships whose construction was funded by the Foundation. *R/V Oceanus*, the first and namesake ship of the class, was delivered late in 1975 and assigned to the Woods Hole Oceanographic Institution, which also carried out the original design studies. *R/V Wecoma*, operated by Oregon State University, was delivered just one month later. The two ships were outfitted by their

respective operating institutions and have been performing capably on full-scale research programs since th spring of 1976. Construction of *R/V Endeavor,* which will be operated by the University of Rhode Island, was completed in October 1976. Outfitting is scheduled for the winter, and *Endeavor* should be in full service early in 1977. Title to all three ships is retained by the Foundation. They are assigned to the operator institutions under renewable 5-year Charter Party Agreements.

The distinguishing features of the *Oceanus* class are flexibility and economy. Although only 177 feet in overall length, they carry a scientific party ranging from 12 to 16 persons, contain over 1,000 square feet of laboratory space, and have a large open afterdeck that allows for easy handling of all types of over-the-side oceanographic gear. Another important design feature is the placement of quarters and laboratories low amidships, where they are least affected by motion. Heavy construction, deep draft, and high freeboard make the ships exceptionally stable, steady, and dry—important characteristics for worldwide, year-round use. Controllable speeds range from dead slow to 15.8 knots, with a cruising speed of 14.5; the controllable pitch propellor, fully trainable bow thruster, and Kort nozzle steering provide full maneuverability under way and on station. The ships have a range of 7,000 miles and 30 days' endurance. Economical operating costs result from a modern engine room, the use of easily maintained standard marine equipment, and the need for a crew of only 12 persons.

With the delivery of *Endeavor,* presently funded construction activity has been completed and NSF is now turning to consideration of future needs. During 1976, the oceanographic facilities and support program funded conceptual design studies and tests of existing designs for a polar research vessel and for coastal ships ranging from 85 to 135 feet in length. These studies should be ready for evaluation early in 1977.

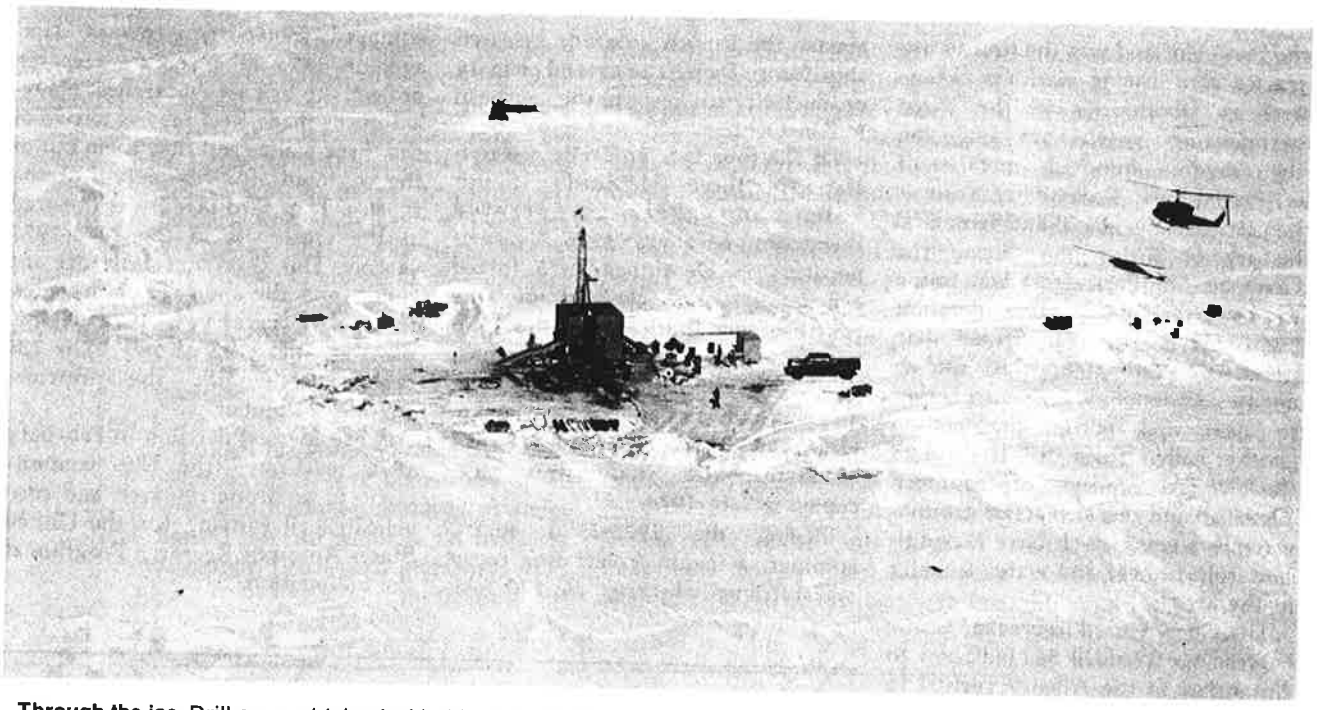
Modern research ship. *R/V ENDEAVOR,* the third of three new oceanographic vessels, was added to the Nation's academic fleet in 1976. This 177-foot-long *OCEANUS*-class ship, designed expressly for research, is being operated by the University of Rhode Island.

The Foundation continues to provide a substantial share of the operational support for the Deep Submergence Research Vessel *Alvin,* operated by Woods Hole as a National Oceanographic Facility. This support is provided under an agreement signed in 1975 by the Foundation, the Department of the Navy, and the National Oceanic and Atmospheric Administration. During 1976, Foundation grantees utilized the unique depth capabilities of *Alvin* for collections, experiments, and observations in fields ranging from microbiology to geophysics.

United States Antarctic Research

A University of Maine glaciologist has shown that, on the Ross Ice Shelf, temperature of the ice at a depth of 10 meters rose 1° C between 1958 and 1974. The temperature at that depth is a proved indicator of average annual air temperature at the surface. Surface temperatures at Byrd and McMurdo stations also rose during this period.

Others have documented the temperature rise in much of the Southern Hemisphere and have suggested that, if the greenhouse effect of increasing atmospheric carbon dioxide causes global warming, the trend probably will become apparent first in Antarctica. However, at the same time the 1° C rise occurred in Antarctica, the Northern



Through the ice. Drill cores obtained with this rig in McMurdo Sound are helping to clarify the glacial and geologic processes in Antarctica over the past 60 million years.

Hemisphere cooled, and the Ross Ice Shelf data alone do not confirm global warming.

Meteorology continued in 1976 as an important part of the U.S. Antarctic Research Program. In addition to routine surface and upper air monitoring at South Pole and McMurdo, research included study of atmospheric chemistry, energy transfer, precipitation from a cloudless sky, and aerosol formation. South Pole is one of the six U.S.-operated stations for global monitoring for climatic change. These stations measure carbon dioxide, ozone, aerosol, and solar radiation levels to identify long-term trends in the concentration of atmospheric constituents that may change climate. To enable collection of data away from stations, one of the antarctic program's LC-130 airplanes was fitted with air sampling ports, sensors, and a logging system. In addition, two air-droppable data-collection buoys were tested near McMurdo.

A University of California group has obtained antarctic data that resolve apparent inconsistencies in models formulated to explain accumulation in the sea of such pollutants as the polychlorinated biphenyls (PCB). PCB has been reported in relatively high concentration in seawater of the North Atlantic and in virtually every marine organism examined from all areas except Antarctica, despite exhaustive analysis of antarctic samples. DDT, however, was present in the antarctic samples. The models attribute entry into the sea almost entirely to atmospheric transport, and it appeared that DDT was reaching Antarctica through the atmosphere while PCB was not.

In a new attempt to determine if PCB was present in antarctic snow, larger samples than those previously examined were obtained by melting and extracting snow *in situ* through polyurethane foam columns. Samples of 100 kilograms or more were processed, permitting detection of PCB in the parts per quadrillion range. PCB was thereby shown to reach Antarctica through the atmosphere, although concentrations were several times lower than those of DDT.

Penguin eggs, including some collected several years previously in which PCB had not been detected, were also reexamined using a technique that removed compounds interfering with analysis for PCB. PCB was detected in all the eggs. All data now are consistent with a model of global atmospheric transport of DDT and PCB.

The United States, Japan, and New Zealand completed a 5-year drilling project in the McMurdo Sound region in 1976. The project resulted in recovery of rock and sediment cores from the deepest holes ever drilled on

the continent and was the first to use sea ice as a drilling platform. Scientists at laboratories in the three participating nations are analyzing the several hundred meters of recovered core. Preliminary analysis has clarified the glacial and geological history of the region during the Cenozoic era. Permafrost was found to be over 400 meters deep at McMurdo Station, far deeper than previously estimated; this finding negates a possibility suggested earlier to heat and power the station geothermally. Holes drilled through the ice-free valleys of southern Victoria Land revealed active groundwater systems, which have a significant role in heat and water transfer in the area.

The Coast Guard icebreaker *Glacier* entered the Weddell Sea (adjacent to Antarctica in the Atlantic sector) to continue a physical oceanographic study begun in the late 1960's. Two bottom-mounted current meters emplaced in 1975 were recovered; the year's data show that northward flow of Antarctic Bottom Water formed in the Weddell Sea is concentrated on the western side and modulated by tidal currents. This dense, nutrient-rich water mass can be traced into the Northern Hemisphere. The ship occupied 55 hydrographic stations, as far south as 67°45′ S. latitude. Salinity-temperature-depth and conductivity-temperature-depth recorders were deployed, and water and krill samples were taken for heavy metal analysis. A Scripps Institution of Oceanography scientist headed the research team.

The ice-strengthened research ship *Islas Orcadas,* operated by Argentina and used cooperatively by Argentine and U.S. scientists, made three cruises in fiscal year 1976. Research was performed in the Scotia Sea to trace fracture zone trends and investigate aseismic ridges in the sea floor, to obtain sediment cores, and to investigate the oceanic polar front zone. Also, U.S. biologists worked aboard the French antarctic research ship *Marion Dufresne* to extend primary productivity studies into the southern Indian Ocean.

Of the four U.S. antarctic research stations, three—McMurdo, South Pole, and Palmer—operated throughout fiscal year 1976. A case of hepatitis in December 1975 forced evacuation and closure of the fourth—Siple Station—for the 1976 austral winter. The station, which supports projects in upper atmosphere physics and is important to the 1976-78 International Magnetospheric Study, was reoccupied in late 1976.

During the 1975-1976 austral summer, a major project was repair and retrieval of three LC-130 (ski-equipped transport) airplanes damaged in 1975 at a remote research project site in East Antarctica. Navy-led teams made field repairs to two of the three planes and flew them out of the continent for completion of the repairs. The third plane was repaired at the crash site in the 1976-1977 season. This diversion of effort and funds, plus the shortage of airplanes, resulted in fiscal year 1976 deployment to Antarctica of only some 130 researchers—half the normal summer's number.

A Presidential decision in February 1976 reaffirmed the U.S. commitment to antarctic research and consolidated all funding for the United States Antarctic Research Program at the Foundation.

Arctic Research

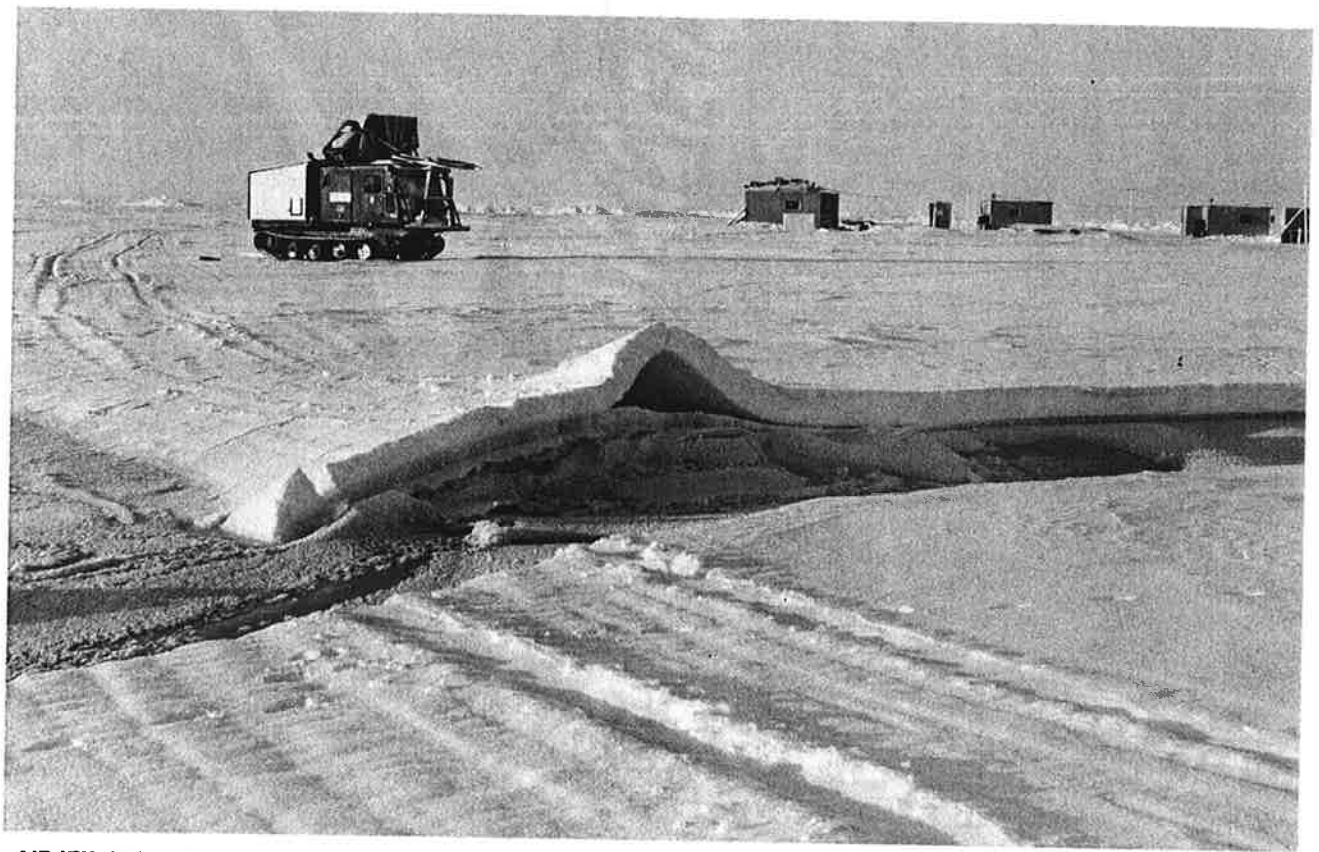
U.S. and Canadian investigators completed a 14-month study in May 1976 of how air, ice, and sea interact in the Arctic Ocean. Four manned camps on sea ice, eight unmanned data-collection buoys interrogated by satellite, remote-sensing airplanes, and a nuclear submarine collected data in a large area 600 kilometers northeast of Barrow, Alaska. The breakup of sea ice in October 1975 forced abandonment of the main camp, but all major goals of the experiment were accomplished. Analysis of the data is in progress and is expected to give the best description to date of the behavior of sea ice in response to atmospheric and oceanic processes. The experiment culminated 5 years of planning and pilot studies. Objectives are to understand the relationship of arctic processes to climate and to improve techniques of ice forecasting. The University of Washington, Seattle, is coordinating the project under contract with NSF.

The second year of the Research on Arctic Tundra Environments project comprised 17 teams involving some 45 scientists from 15 universities. The work was conducted at two sites on the North Slope of Alaska. Terrestrial studies were done at Meade River to characterize the land forms and vegetational communities, measure the physiological response of plants to physical conditions, and assess the effect of grazers on vegetation. Mapping of soil and vegetation is completed; experiments on grazing effects are in progress. Aquatic studies at Toolik Lake, near the trans-Alaska pipeline route, have quantified the biological structure and trophic levels, developed a model of biological productivity, yielded data on environmental and recreational stresses, and developed mathematical models for predicting biological consequences of various disturbances. The Cold Regions Research and Engineering Laboratory, Hanover, N.H., is the coordinating office.

Geophysicists from St. Louis University, working with scientists from Poland, West Germany, and Norway, set up portable seismic stations on Svalbard during the summer of 1976. Earthquake epicenters were located and analyzed to help determine the present tectonic activity of this area of the arctic continental shelf. The group set off large explosions and measured the sound waves at distances of 100 and 200 kilometers as they passed through the deep crust of the Earth beneath Svalbard. These data will help to determine crustal structure and composition.

The Foundation published a comprehensive statement of federally supported arctic research performed in fiscal 1976; it is available from the Division of Polar Programs.

North Slope. At Meade River, Alaska, researchers continue studies of the impacts of grazing and other ecological stresses on the fragile tundra environment.



AIDJEX. This main camp was one of four manned installations established on the sea ice 600 kilometers northeast of Barrow, Alaska, for a study of air/ice/sea interactions and possible effects on climate in the arctic. (Photo by Norbert Untersteiner.)

Biological, Behavioral, and Social Sciences

3

A reorganization of the Foundation in July 1975 resulted in the setting up of the Biological, Behavioral, and Social Sciences programs as a separate administrative entity within NSF. Research in these programs ranges from studies on the fundamental molecules of life to the complex interactions of human beings and societal organizations; collectively and individually, the research deals with some of today's major scientific challenges and rewarding discoveries.

Although the Nation has made remarkable advances toward alleviating the pressing problems of food, population, health, energy, and environment, many of the longer term solutions will be found within the constraints of new biological knowledge and the limits of our understanding of humankind. The problems in biological, behavioral, and social sciences are attracting considerable intellectual talent and effort; the results of this research will be ripe for exploitation over the next several decades. In furthering basic knowledge in these important fields, it is our expectation that the Nation's research capabilities on natural and social phenomena will be strengthened in a significant manner.

This is perhaps best illustrated in those areas in which the Foundation assumes equal or "lead" agency status in contributing to the Federal efforts in support of basic academic research. In the social sciences NSF provides 58 percent of the Federal support to universities, ranging from 36 percent in economics to 93 percent in political science. Approximately 70 percent of the basic research in ecology is supported by NSF, and in systematic biology the Foundation is the primary source of support for academic research.

NSF's reorganization in early fiscal year 1976 brought with it new recognition of the Foundation's responsibilities in the behavioral and neural sciences. Neuroscience is among the fastest growing of the sciences, attracting increasing numbers of young scientists as well as established ones who are changing fields to undertake the challenge of understanding how the nervous system and brain function. Also, because basic research in the psychological sciences, anthropology, and linguistics has received diminished Federal support in recent years from other agencies, the Foundation's responsibility has increased consonant with new scientific opportunities in these areas.

The Foundation also has taken on greater responsibility in the plant sciences, a research effort of immense importance to the world's food problems. Although support for this work has grown to approximately one-third of that available in NSF's basic research in the biological sciences, with somewhat larger amounts available from other agencies, there are still many promising areas of research going unexplored. These opportunities arise from new techniques for manipulating plant cells experimentally and recent instrumentation that allows plant processes to be quantified more accurately and rapidly in both laboratory and field situations.

Table 4
Biological, Behavioral, and Social Sciences
Fiscal Years 1974, 1975, 1976
and Transition Quarter (July 1-Sept. 30, 1976)

(Dollars in Millions)

	Fiscal Year 1974		Fiscal Year 1975		Fiscal Year 1976		Transition Quarter	
	Number	Amount	Number	Amount	Number	Amount	Number	Amount
Physiology, Cellular and Molecular Biology	994	$36.85	1,006	$ 41.87	1,053	$ 43.69	279	$12.00
Behavioral and Neural Sciences	468	15.23	547	18.50	539	19.69	140	5.47
Environmental Biology	398	21.78	487	26.05	534	26.84	156	7.15
Social Sciences	405	18.81	359	17.75	364	18.81	100	5.11
Total	**2,265**	**$92.67**	**2,399**	**$104.17**	**2,490**	**$109.03**	**675**	**$29.73**

Physiology, Cellular, and Molecular Biology

Research supported by the physiology, cellular, and molecular biology program is concerned with fundamental phenomena central to all biological research: cellular and subcellular activities that affect activities and functions of an entire plant or animal. It has become apparent during 1976 that we are entering an era in which the discoveries and concepts of the past are being extended to explain phenomena at higher levels of complexity: namely, from cells and cell systems to higher organisms, including man. Researchers in this area currently are experiencing the excitement of discovery and an information explosion comparable to those that launched the "new biology" more than two decades ago.

The current concentration of research at higher levels of complexity is due to a number of factors. To a greater extent than ever before basic researchers are directing their efforts to challenges that have obvious relevance to problems of health and agriculture. Disciplinary boundaries in biology have virtually disappeared, and much of today's research is problem-oriented, approached with multidisciplinary methodologies. Major factors that have catapulted biological research with complex systems to new levels of sophistication are the development and adaptation of advanced instrumentation and refinements in technique. For instance, a variety of cell types now can be maintained under laboratory conditions in which they can grow, divide, and be experimentally manipulated. With the use of biochemical, biophysical, genetic, and physiological methodologies, the dynamic processes of these cells—such as cellular division, growth, differentiation, specialized functions, movement, and communication—can now be analyzed quantitatively. Also, with new understanding of viruses that infect higher plant and animal cells, researchers can now use these viruses as probes within cells to modify specific cell functions in controlled ways—for instance, to alter, initiate, and inhibit certain cell processes.

New techniques have been developed for isolating and analyzing subcellular structures such as ribosomes, mitochondria, and chloroplasts. These structures, as well as chromosomes and other aggregates of complex biopolymers, can be studied to determine the relationship of their molecular structure and organization to their functional properties. This type of analysis is at an early stage but is attracting sufficient attention so that rapid progress can be anticipated in understanding many phenomena: for example, how enzymes effect catalysis, how genes are turned "on" and "off," the rationale of the genetic code and the spatial arrangement of genes on chromosomes, the activities of the ribosomal machinery during protein synthesis, and the intricacies of energy transduction in chloroplasts and mitochondria.

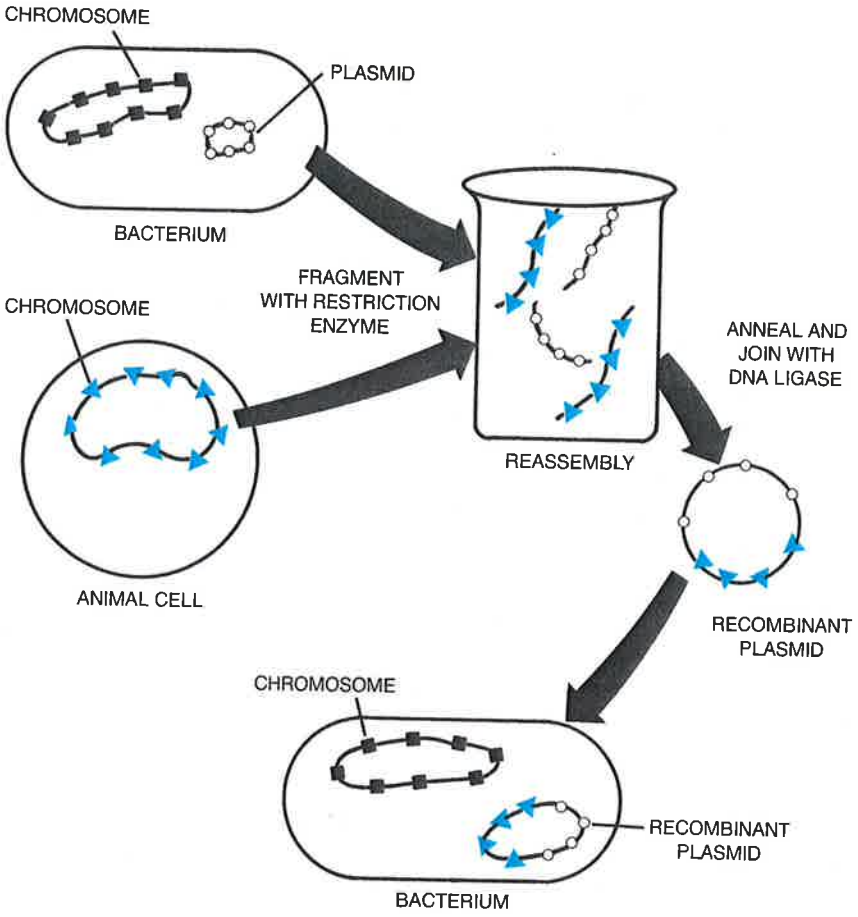
Major technical advances that may be expected to have a marked effect on the direction and rate of progress in biological research include the development of methodologies that permit the analysis and experimental manipulation of genetic material. Foremost of these advances is the discovery of the mode of action of restriction enzymes and the subsequent use of this knowledge for mapping the genetic material at the nucleotide level. For example, hybrid DNA molecules can be propagated *in vitro* and then transposed to a host cell. The cleavage of DNA by restriction enzymes coupled with techniques such as gel electrophoresis, filter hybridization, and use of the electron microscope for visualizing individual DNA molecules provide a new level of analytical resolving power for biological problems that previously could not be attacked. In theory, it is now possible to analyze genetically at the molecular level any animal, plant, or virus, including those that are not amenable to genetic analysis by traditional methods. Individual genes and the elements that control their activity and their products can be isolated and studied with respect to structure and function. This new approach for studying intracellular regulation in higher organisms is particularly significant because this has been a relatively intractable area.

Gene Structure and Function

One of the most exciting and rapidly moving areas of basic research in modern biology is the study of the relationships between the structure and function of genes—in organisms as primitive as bacteria to those as complicated as man. Such research crosses the boundaries of genetics; biochemistry; and molecular, cell, and developmental biology, thereby representing an interdisciplinary approach that uses the most powerful tools of each discipline.

The theoretical and practical cornerstones of this research rely on the fact that restriction enzymes are available which can break two DNA molecules from different biological origins so that they can subsequently be spliced together to make a hybrid or chimeric molecule. By the addition of special enzymes called polymerases and ligases, the hybrid molecule, containing the particular genes under investigation plus those genes that allow replication to occur, become biologically inseparable.

The Foundation is supporting important basic research dealing with



Gene isolation and amplification. A new research technique of immense potential for understanding the details of how genes function makes use of restriction enzymes. There exist in certain bacteria small rings of DNA carrying a few genes separate from the bacteria's chromosomes. These rings, or plasmids, can be broken by the restriction enzyme, as can DNA from an animal cell. When mixed, parts of these two different kinds of DNA can be recombined into a new plasmid, which can then by introduced to the bacterium and reproduced in great numbers for further study.

the theory and practice of gene isolation and amplification, the ability to make multiple gene copies. The results and benefits from this research should be both immediate and far-reaching, including a fundamental understanding of how genes are expressed and controlled to how they replicate and recombine.

- A research team at the University of California, San Diego, is studying the mechanism by which certain genes can control the fixation of atmospheric carbon dioxide in plants, a physiological process fundamental to all life forms on our planet.
- At Harvard University, a group is pursuing the genes responsible for nitrogen fixation by special bacteria which are attached to the roots of legumes such as soybeans, peanuts, and peas and which are responsible for the primary source of organic nitrogen necessary for growth of food crops.
- A second Harvard group is examining how genes for the nucleic acid component of ribosomes are controlled. These are genes that ultimately affect the phenotype of an organism by influencing the types of proteins that the cell produces and their rates of synthesis.
- Genes isolated from the fruit fly, *Drosophila*, in a Stanford University laboratory are being used as a model system to study how repetitive sequences in the histone genes affect the way genes act and are controlled under hormonal influence.
- A University of California, San Francisco, team is studying the topological organization of multiple copies of mitochondrial genes, while another group at the University of Iowa is investigating the mechanisms by which these genes orchestrate mitochondrial protein synthesis. Since mitochondria are the powerhouses of a cell, the fundamental differences between the organization of cellular and of mitochondrial genes must be explored to elucidate the various ways in which informational potential is finally expressed.
- Hemoglobin is an essential component of blood in that it carries oxygen to all vital tissues and organs. A Harvard University laboratory is examining how rabbit globin genes affect hemoglobin synthesis by studying both the regulatory gene sequences and the mechanisms by which these genes are transcribed. A research team at Yale University is studying both the normal and thalassemia globin genes from human beings. In addition to clarifying the methods by which normal genes act and are controlled, this study also has provided a comparative analysis of an abnormal

counterpart of the human hemoglobin gene.

Various stages of gene amplification have been accomplished in each of these systems. Research made possible by this amplification is, in most cases, just beginning. However, at least two of the studies already have produced important results. The Harvard group, which is studying genes responsible for nitrogen fixation, has taken a first step toward giving nonleguminous plants the biological capacity for nitrogen fixation. This group has made two important recent advances. First, the bacterial replication vehicle, to which the two groups of nitrogen-fixation genes have been joined, has been shown to survive transfer to plant cells. Second, two independent replication vehicles have been constructed, each containing a bloc of the nitrogen-fixation genes. One of these hybrid units has been cloned; the other will be cloned shortly. The next step is to select a recombinant replication vehicle containing both sets of nitrogen-fixation genes to attempt insertion into plant cells. The Stanford University group, studying the histone genes from *Drosophila*, has isolated the histone messenger RNA and has determined the length of the messenger and the way in which it is processed by the cell to unit size. This is accomplished by the formation of special loops between the histone gene DNA and the messenger RNA that is transcribed and processed from it.

A very different approach toward the goal of understanding gene structure and function also has been under way for the past decade. At the Massachusetts Institute of Technology a gene that codes for a suppressor transfer RNA for the amino acid tyrosine has been synthesized with "off-the-shelf" chemicals. The research team has shown unequivocally that the 199-unit polynucleotide consists of both the start-and-stop portion of the gene as well as the gene itself. After its synthesis from nucleotide units and development into short single-stranded chains, the complete structure was introduced into a bacterial strain that previously lacked this function. The result was a complete restoration of normal function to the bacterial cell.

Advances in Photosynthesis

Our ability to produce adequate foodstuffs for future generations will be linked, in part, to our ability to increase crop productivity; some technologies for increased productivity of agricultural crops depend, in turn, on a basic understanding of plants. One of the most important aspects of plant science is the process of photosynthesis, wherein solar energy converts carbon dioxide in the plants into biochemicals necessary for plant growth.

NSF-supported research in this area has dealt with various aspects of photosynthesis, from the capture of photons (sunlight energy) by chlorophyll to the synthesis of chains of carbon atoms, and including the actions and control of genes involved in the process. Researchers at the Universities of Rochester and California, Berkeley, have been studying the way in which light energy is "captured" by chlorophyll molecules and funneled to the "reaction centers," discrete complexes of chlorophyll and other molecules, where the actual transformation of light to electrical energy occurs. Considerable progress has been made at the University of Washington, University of California, San Diego, University of Pennsylvania, and City University of New York in clarifying the process of energy transduction in the reaction centers of plants and photosynthetic bacteria in terms of time sequence and the nature of the molecules involved.

After the electron has been separated from the chlorophyll in the reaction centers, the electron is "transferred" through a complex sequence of "acceptors" for eventual use in the manufacture of carbohydrate. Numerous proteins, often associated with the plant membranes, are involved in this electron transport process, which is coupled to the production of high-energy compounds necessary for driving fundamental biochemical reactions in the plant. Of particular interest among the many research projects on this electron transport and production of high-energy compounds is work at Purdue on the basic interpretation of light-induced potentials in photosynthetic membranes and the question of whether hydrogen ion gradients are coupled to active transport processes.

A new technology based on a photoelectron microscope developed at the University of Oregon and the Oregon Graduate Center will enable scientists to study chlorophyll and other pigment complexes in the photosynthetic membranes of plant chloroplasts. This microscope shows images of electrons selectively ejected from the chlorophyll by a laser beam. With specific lateral and depth resolution, it will be possible to determine the location and concentration of the pigment within the membranes. This technique has the potential to yield further information on the pathways of electron flow during photosynthesis.

Advances in Nitrogen Fixation

A research area spanning the whole spectrum of NSF's physiology, cellular, and molecular biology program concerns the process of nitrogen fixation by rhizobia, the particular bacteria on roots of leguminous plants. In addition to the genetic work mentioned previously, progress is being made in numerous other aspects of the process. Basic work at Stanford on the iron-

molybdenum protein of the complex enzyme, nitrogenase, that catalyzes the reduction of nitrogen, has provided new information on the chemical state and environment of the molybdenum atom. Similarly, investigations at Wisconsin and Minnesota have further illuminated the chemical state and environment of the iron atom in both the iron and iron-molybdenum proteins. In addition to this work on the catalytic site, scientists at Wisconsin and Purdue have characterized further the subunit structure of the enzyme, as well as the nature and regulation of the metabolic pathway in nitrogen fixation.

The question of how rhizobia are attracted to the roots of legumes where nitrogen-fixing nodules are formed is a crucial facet of the whole process, an example of the general area of investigation involving chemical specificity. Work being conducted at Colorado, Montana State, and the University of Minnesota is in the process of elucidating this topic. Various aspects of work at the molecular and submolecular level are enabling enzymologists, geneticists, bioengineers, and crop specialists to determine life processes of plants and animals—and ultimately to provide knowledge that will assist in increasing plant productivity.

Behavioral and Neural Sciences

The behavioral and neural sciences continue to be among the most rapidly developing areas of science. During the past year the behavioral and neural sciences programs were reorganized within the Foundation to focus research on human and animal behavior and the organ-system that directly underlies behavior—the nervous system.

One of the most important recent findings in the neurosciences is the demonstration of "sprouting" or growth of nerve axons from an adult animal *in vitro* (outside the organism), indicating a much greater capacity for growth and change in the nervous system than was thought previously to be the case. Other important findings include the identification of a number of previously unknown chemical neurotransmitters responsible for excitation or inhibition of neurons in the brain. Using simple invertebrate animals, researchers have shown that the learning process results from changes in synaptic transmission at critical junctions in the brain's neural circuit. New methods of technology, including autoradiographic and enzyme tracer techniques to delineate nerve pathways and the use of computer technology for three-dimensional reconstruction of neurons and anatomical relationships of entire nervous systems of small organisms, have provided increased opportunities to understand the fine structure and function of the brain.

Understanding the development of the brain and of human behavior is a key objective of the behavioral and neural sciences. From studies with infant animals, there is much evidence that the nervous systems—and hence the behavior—of animals may be affected permanently by environmental events during critical periods of early life. Such research may provide the basis for understanding the effects of early deprivation in the lives of children. Another research area in which work with animals has begun to improve our capabilities for dealing with human problems is that of language learning by chimpanzees. Training procedures in communications developed with chimpanzees have proved valuable for training language-deficient children. Also, parallel findings in research with children and chimpanzees show that the processes of language development can now for the first time be studied under scientifically controlled conditions. One such finding shows that concepts in both children and chimpanzees develop before language labels are attached to them. This implies that early language development is not simply a matter of imitating adult language but requires the prior maturation of cognitive functioning. An offshoot of teaching sign language to chimpanzees is a new interest by linguists in the use of sign language by deaf people.

Research on cognitive processes (sometimes called "higher mental processes") has created a great deal of excitement in the past year. One approach, called information processing, analyzes complex mental operations into functional subprocesses. These subprocesses, bearing a variety of technical names, allow important distinctions to be made when disease or other factors interfere with human learning, memory, or thought. To focus most effectively on current and expected advances in this area, a new NSF program, memory and cognitive processes, was formed during fiscal year 1976.

A second new program, sensory physiology and perception, was established formally to be responsive to the rapid developments occurring in research on all sensory systems involved in receiving information from the environment—especially vision and hearing. Knowledge of the fundamental nature of hearing, for example, has been advanced significantly through recent research in microanatomy, electrophysiology, and human and animal psychophysics. A particularly important research area deals with a type of

hearing loss, called presbycusis, that accompanies aging.

Knowledge of cultural phenomena also has advanced significantly in the past year. As an example, large-scale research concerning unbiased evaluations of social programs is beginning to produce important results. Sources of bias in the early evaluation of such national programs as Head Start have been identified and corrected, with the resulting reanalysis showing more beneficial effects of this program than those previously estimated. In another area, social psychological research has focused on how persons respond to experience with events that are out of their control. The results indicate that such experiences can cause individuals to become passive in the face of seemingly uncontrollable, but later controllable, events. Current efforts are focusing on how such "learned helplessness" may be overcome.

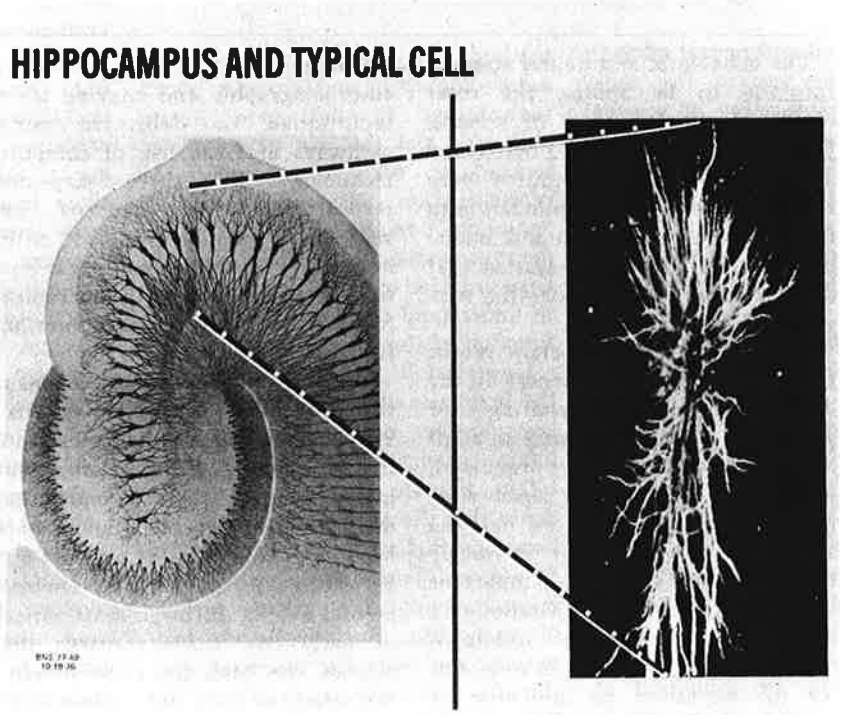
In the field of anthropology, research conducted by U.S. scientists in Africa and Asia has shown new evidence indicating the origins of man as early as 3½ million years ago. Archaeological research on agricultural technologies suggests that early irrigation techniques may have been more efficient than those in use today. Another investigation produced the interesting finding that even in prehistoric times the concentration of mercury in fish was well above the concentrations in the surrounding environment.

During the year, NSF's programs in behavioral and neural sciences, together with those of the social sciences, were reviewed by a special committee of the National Academy of Sciences. Possibly the most important general recommendation presented in the final report, *Social and Behavioral Science in the National Science Foundation,* is the need for larger scale research efforts than have been supported regularly in the past in these fields. Initiatives in response to the recommendation are under way.

Adaptability of the Brain

Plasticity or adaptability is the most salient characteristic of the brain; the brain's adaptability expresses itself in nearly all central nervous system operations, but especially in recovery from damage. A dramatic example of such recovery is the case of a young American soldier in the Korean campaign who sustained a massive brain wound involving the left parieto-tempero-occipital area. At first he was totally unable to speak, but in 3 months he was using two-word sentences. Eight years later, he had recovered fully and exhibited normal speech. Neuroscientists have long been concerned with the problem of how the brain is so marvelously flexible, and various approaches have been taken to study this plasticity. This flexibility is especially pronounced during early development, and increasing attention to how the brain changes during this period has been particularly fruitful. Newer findings suggest the flexibility persists at older ages.

Gary S. Lynch of the University of California, Irvine, has successfully used a number of biological techniques to detect the processes by which the brain recovers after being damaged. Lynch first showed that axonal sprouting (nerve growth) takes place in the hippocampus part of the adult rat brain in response to a lesion. He used both light and electron microscopy to "map" the extent of the sprouting and used biochemical



Nerve growth in the brain. The hippocampus, a part of the brain implicated in emotion, visceral activity, short-term memory, and other behavior, has recently been shown to "sprout" new nerve cells in response to injury. An experimental technique has now been devised to study sprouting from normal hippocampus tissue removed from the brain, a step of great importance in understanding mechanisms underlying this neural plasticity.

and electrophysiological experiments to verify that this new growth was indeed functional. These initial experiments were carried out *in vivo* (in the living species) for several years and clearly established sprouting in the brain as a reproducible phenomenon.

As the research progressed, however, it became clear that there were limitations to a strictly *in vivo* analysis. For example, the sprouting is preceded by a tremendous proliferation of glial cells (non-nerve cells in the brain) in the region into which the nerves would later grow. *In vivo*, it was impossible to determine the underlying molecular mechanisms. Considerations of this sort led Lynch to develop a device where sprouting could be studied *in vitro*, outside the organism, in a much more controlled manner. After much difficulty, this young investigator devised a special chamber in which "slices" of the hippocampus could be maintained as normal (nonlesioned) brain tissue. He then developed additional new techniques necessary to study sprouting. in this chamber. These pioneering techniques have benefited many other neuroscientists.

Lynch is now searching for the specific substances that underlie sprouting in slices of brain tissue where he can more easily detect and measure changes. For example, he is determining what materials are released by the slices to trigger the proliferation of glial cells and if slices from normal hippocampus release materials that suppress the glial proliferation. Once these substances are identified and characterized, he plans to reintroduce them into the whole animal to verify their molecular actions and determine their behavioral effects. This work has provided scientists with a method of manipulating one form of neural plasticity and of understanding its underlying molecular mechanisms.

Although Lynch's work has had unusual impact upon the neurosciences, his approach is characteristic of many superbly trained young neuroscientists. In contrast to a decade ago when a neuroscientist tended to be either a neuroanatomist, a neurochemist, a neurophysiologist, or a neuropsychologist, today neuroscientists are oriented toward a given problem and attempt to bring the full technological range of modern biological methods derived from a number of disciplines to bear on that problem. This approach more than any other single factor underlies the success of Lynch's research program.

Hearing Loss—Presbycusis

The hearing ability of humans and many other animals deteriorates with increasing age. The loss of hearing, called presbycusis, is so widespread in today's society that essentially every man and woman eventually encounters it. Presbycusis is typically more severe for men than women, and it occurs more rapidly at high frequencies of sound than at low. The first recorded incidence of presbycusis is found in records indicating that Egyptians sustained permanent hearing loss centuries ago as a result of living along the Cataracts of the Nile. While many scientists have argued that specific changes in the auditory system are directly caused or facilitated by a noisy environment, it is not clear if the changes result from exposure to noise or are due to general physiological aging.

Harlow W. Ades of the School of Electrical Engineering at the University of Illinois and his associates recently have documented neuroanatomical changes in the auditory system that apparently occur only in auditory mechanisms of individuals of advanced age. They conducted postmortem studies on the vestibular sensory epithelia and sensory nerve fibers in elderly humans and found a considerable reduction in both the number and diameter of nerve fibers serving the auditory mechanisms as well as a parallel reduction in the number of receptor cells. However, it is difficult to obtain well preserved human material, and the observed modifications may have been produced by some external agent; it was desirable for Ades to compare these results with those obtained on inner ears from aged nonhuman primates, preserved under controlled laboratory conditions. The early results of these investigations confirm the findings in humans.

Working in conjunction with the Yerkes Primate Center in Atlanta, Ga., Ades and his associates discovered several anatomical changes in aged primates which may be related to the presbycusis phenomenon. For example, abnormal changes were found in the structure of the membrane between the sensory hair cells of the cochlea (inner ear) and the fibers that are primarily responsible for transmitting auditory information to the central nervous system. These changes occur at the afferent synaptic junction and appear to be of sufficient magnitude to impede normal synaptic activity.

Various other changes appear in the aged cochlea. For instance, there is a formation of large vacuoles and a significant intracellular accumulation of lipo-fuscin (a biochemical product of deterioration) in the specific sensory and supporting Deiters cells. There is also an abnormally developed laminated structure that projects from the cuticular plate above the hair cell into the receptor cell itself. (Although this structure may be present in young animals, it increases in size and length with increasing age.) Also, the number of macrophage cells in the inner ear increases.

Ades and his associates are involved in a continuing effort primarily addressed to two questions: (1) Are the neuroanatomical changes ob-

served in aged cochlear and vestibular mechanisms similar to the neuroanatomical effects caused by intense noise? and (2) Are auditory mechanisms that have deteriorated because of the aging process more susceptible to noise than "pristine" ears?

From the results of this research, our knowledge of the aging process and the effects of noise on the auditory system will be greatly expanded.

Environmental Biology

Major parts of systematic biology and ecology, the core disciplines of NSF's environmental biology programs, have undergone profound transitions during recent years. Until recently systematics—the classification of plants and animals to indicate natural relationships—could only infer genetic relationships from readily discernible anatomical similarities. Since the 1950's, however, knowledge of the molecular structure of proteins and of DNA (deoxyribose nucleic acid) in certain taxonomic groups, particularly vertebrates, has made it possible to inquire directly about the similarities or differences in the molecular structure of organisms. By comparing similar classes of protein molecules that can be isolated easily in reasonably pure form—blood proteins such as hemoglobin and albumin—the readily detected differences in the amino acid sequence of the molecules can be attributed to differences in structural genes, that is, the DNA sequences that code for these proteins.

The hypothesis underlying studies of Allan C. Wilson and associates at the University of California, Berkeley, was that careful examination of the products of specific structural genes from groups that experienced contrasting rates of organismal change would provide information on the mutation rates of the genes and possibly on the rates of evolution in different species of organisms. But contrary to expectations, the work suggests that the mutation rates of structural genes appear to be largely independent of rates of evolution as judged by anatomical characteristics of the species. For example, Wilson and his coworkers have evidence that albumin has evolved at about the same rate in frogs and mammals. Further, they have compared 44 proteins of humans and chimpanzees and found them 99 percent identical; yet, from a traditional anatomical basis the two primate species are classified in different families.

Although only a few of the structural proteins have been compared, the evidence suggests strongly that the rates of DNA change in structural genes have little relation to rates of overall evolution of the species themselves. Since the slow rate of change in the DNA of structural genes appears not to explain organismal evolution, Wilson is now testing the hypothesis that the basis for adaptive evolution of organisms is primarily through the mutation rate of the "regulatory genes"—genes that control the activation of the structural genes. Wilson argues that the mode of action of regulatory genes known to function in bacterial systems will be applicable to higher organisms. Through their work, Wilson and his coworkers have sharpened the focus of molecular evolution and have undertaken challenging studies on the evolutionary significance of "regulatory genes." This ambitious project will provide definitive results only slowly, but the continued use of sequence methodology is likely to provide more accurate information on divergence lineages, especially in cases where the fossil record is poor.

Community ecology has constituted the intellectual core of the science of ecology since its beginning early in this century. It is still thriving, asking new questions, delving deeper into ones long asked. The nature of coadaptive interactions between plants and the insects that feed upon them, for example, has long piqued the interest of ecologists. On the basis of new knowledge, for example, of the biochemical identity of a variety of "secondary substances" that plants are known to produce, more sophisticated ecological insights are emerging. New techniques of microchemical analysis are paving the way for the study of the population genetic aspects of the relationships as well.

During the past decade two disciplinary offshoots of systematics and ecology have developed: population biology and ecosystem science. Various lines of investigation by community ecologists and by systematists are coming to focus more precisely on multifaceted analyses of the biology of natural populations. The facets include population genetics, behavior, and physiology, as well as ecological relationships.

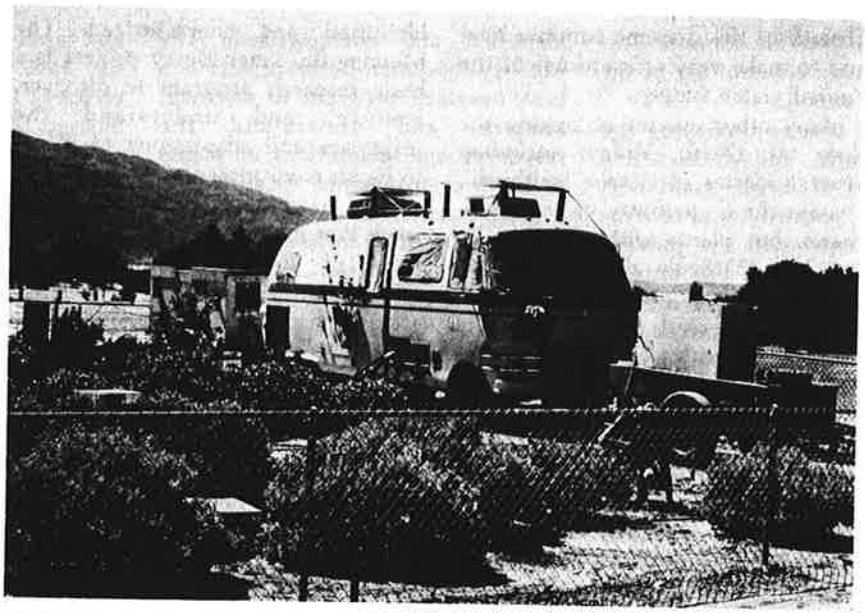
Ecosystem science, embodying an approach that was evident early in the history of ecology, has made substantial progress through the U.S. biome programs under the auspices of the International Biological Program (IBP). IBP completed its existence as a formal organization several years ago, but the support of some of these large integrated projects has continued. During fiscal year 1976 these biome projects were in varying stages of completion, and a second generation of integrated ecosystem research projects, smaller in scale, was begun—a measure of the

initial programs' success. In large part the new studies extend and refine insights, information, and techniques developed in the IBP-initiated projects. The taiga ecosystem study in Alaska, a prime example, was formulated mainly by scientists who participated in the Tundra Biome project.

Adaptations of Plants to Extreme Environments

Harold Mooney of Stanford University and Olle Björkman and Joseph Berry of the Carnegie Institution of Washington are trying to bridge the gap that exists between investigations of field ecology, whole plant physiology, and studies at the cellular and subcellular levels. They are attempting to uncover the adaptive mechanisms that enable certain higher plants to tolerate, and in some cases even thrive, in stress environments that are lethal to plants in general. For this purpose they are comparing the performance of plants occupying habitats that are extreme in one respect or another.

One such environment is the desert floor of Death Valley, Calif., one of the hottest and most arid environments on Earth. In summer, the plants must tolerate temperatures that often reach or even exceed 50° C (122° F), while at the same time having to cope with extremely dry air (about 5 percent relative humidity) and very limited water supply. Plants that are active and able to grow under these conditions must have special adaptations to resist thermal and drought injury and at the same time be able to carry out photosynthesis with a high efficiency of water use. With the aid of a specially equipped mobile laboratory and an experimental transplant garden, these investigators are able to study the productivity and key physiological processes, such as photosynthesis, on extreme desert plants in their native sites and also to compare them with



Transplant garden. Scientists studying the tolerance of desert plants to the extreme environment of Death Valley, Calif., are trying to learn more about the adaptive mechanisms that enable plants to survive under such conditions. Such research may be useful in the development of new kinds of food crops that can be grown under desert conditions.

those of plants transplanted from contrasting climates such as cool oceanic habitats. Further studies on these plants, grown under a series of precisely controlled environments in the Carnegie laboratory at Stanford, permit these workers to separate the effects of various stress factors, such as high temperatures and severe drought, as well as to analyze the component growth processes and the properties of cellular components such as chloroplast membranes and enzymes.

The research reveals striking differences among higher plants with regard to their capacities to utilize water, photosynthesize, grow, and survive. Probably the most spectacular example is *Tidestromia oblongifolia*, native to the floor of Death Valley. This remarkable plant has its peak activity, with very rapid growth, during the hottest part of the year, but is dormant during the mild winter and spring. The optimum rate of photosynthesis and growth occurs at about 46° C (115° F), and its productivity exceeds that of most plants on Earth even in lush climates with moderate temperatures and ample water supply. The ability of *Tidestromia* and several other hot desert plants, such as the creosote bush, *Larrea divaricata*, to endure extreme heat which is lethal to plants from temperate climates is in large part due to an unusually high thermal stability of their photosynthetic machinery, involving components of the chloroplast membranes responsible for photochemical activity as well as enzymes of the CO_2-fixing system. *Tidestromia* (and numerous other species from 15 families, mostly of dry tropical and subtropical origin) also possesses an especially efficient mechanism for CO_2 fixation, called the C_4 pathway of photosynthesis. This pathway, in combination with the unusual heat stability of its photosynthetic apparatus, enables *Tidestromia* to maintain extraordinarily fast rates of photosynthesis and

growth in the extreme summer heat and to make very efficient use of the limited water supply.

Many other species occupying the floor of Death Valley, including several species of *Atriplex* (saltbush), possess the C_4 pathway of photosynthesis, but plants with the conventional C_3 pathway also are present and have developed special mechanisms for survival. For example, the evergreen shrub, *Larrea divaricata*, is capable of seasonally adjusting its photosynthetic temperature dependence in an adaptive manner. Perhaps the most striking feature of this species is its ability not only to endure very high levels of water stress but also to photosynthesize at normal rates even when, as a consequence of low soil moisture and very dry air, the water potential of the plant has fallen to very low levels (-35 to -40 bars). In plants from moderate climates, photosynthesis usually ceases at about -10 to -15 bars, and prolonged stress below -17 bars generally is lethal. The mechanisms responsible for the ability of *Larrea* and certain other desert plants, including *Atriplex hymenelytra*, to retain normal rates of photosynthesis under severe drought are currently the subject of intensive study by the Carnegie-Stanford Group.

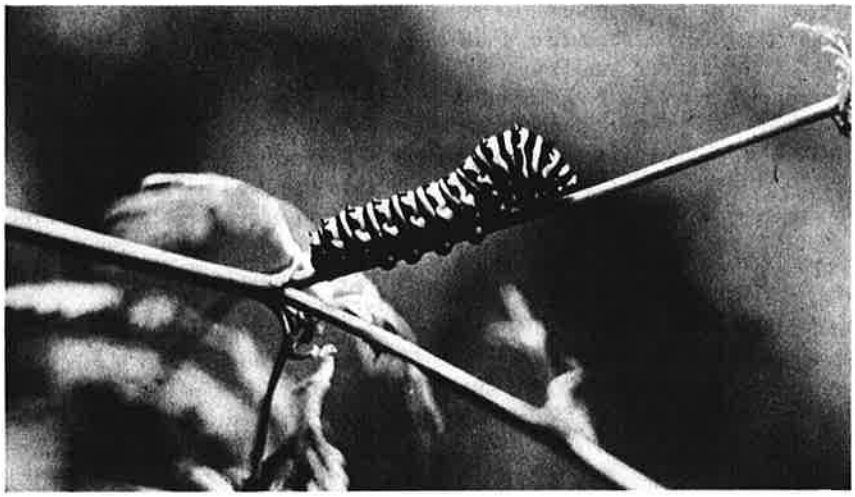
Another interesting and potentially useful aspect of the research is the genetic studies in which C_4 species and C_3 species of *Atriplex* are hybridized in order to determine the mode of inheritance of the C_4 photosynthetic pathway. It would, of course, be enormously useful if scientists could discover how some of the characteristics of desert-adapted plants could be introduced into plants that are useful for food, fiber, fodder for animals, fuel, or even soil stabilization. Introduction of such adaptations through plant breeding probably will be very difficult. However, before the feasibility of such efforts can be evaluated, it is, of course, necessary that these adaptive mechanisms be identified and characterized. The Mooney-Björkman-Berry project is a basic research program to discover, analyze, and understand the responses and adaptations of plants to harsh environments. As such, it is a good example of the fundamental work that must underlie the development of crops that can tolerate environmental stresses and make efficient use of limited resources.

Plants and Their Insect Herbivores

Most plants synthesize compounds that have the effect of protecting them from attack by insects. Not surprisingly, in the course of time herbivorous insects have developed metabolic systems to detoxify these noxious plant compounds. These relationships between plants and insects are of increasing interest because they may have led to the use of "natural" strategies for plant protection. In an effort to learn more about these relationships, Paul Feeny and his coworkers at Cornell University have been studying the chemical ecology, energetics, and population biology of two closely related, leaf-eating, swallowtail butterflies that live in the Ithaca, N.Y., area but which feed in quite different situations.

The black swallowtail, *Papilio polyxenes*, feeds on the wild carrot and its relatives of the umbellifer family. Leaves of wild carrot, with relatively high contents of nitrogen, sodium, and water, provide a nutritious, though somewhat sparsely dispersed, food source for the black swallowtail, which detoxifies the specific qualitative poisons that act as barriers to many other insect species. The second species, the tiger swallowtail, *P. glaucus*, feeds on the leaves of many families of forest trees. While the canopy of these trees is a seemingly abundant food source, it is not nutritious since it is relatively low in the nitrogen, water, and sodium required by growing insects.

The scientists have found that



Plant defense strategies. This caterpillar of the black swallowtail butterfly is one of the few insects able to eat and tolerate the specific chemicals in this annual umbellifer plant. Community ecologists suggest that many plants use chemical defense mechanisms such as this, in which only a few insect species can locate and adapt to that food supply. On the other hand, leaves of longstanding perennial plants, such as trees, are subject to being eaten by many species of insects. They tend to develop general, multiple toxins that act to limit the population growth of their insect predators. (Photo by Paul Feeny/Cornell University.)

black swallowtail caterpillars feeding on the weedy wild carrot mature in 3 weeks. Caterpillars of the tiger swallowtail, feeding on the forest canopy, however, take 8 weeks to mature. Compounding the retardant effect of the low nutritive level of the tree leaves is the presence of tannins and terpenes, both of which interfere with the insect's utilization of the nitrogen present in the leaves.

Drawing on these observations, Feeny and his coworkers have developed a general hypothesis about the nature and consequences of the consistent and predictable differences in chemical defenses of plants that characterize recently disturbed areas as compared with those of more stable areas. The disturbed areas typically are dominated by a diversity of short-lived (annual) plants, many of which make small amounts of highly toxic chemicals that absolutely repel most herbivorous insects. A few insects have the ability to detoxify the compounds made by different annual plant species. The black swallowtail, for example, is one of the few to feed upon the umbellifer plants such as wild carrots. The larvae of the cabbage butterfly select plants such as wild crucifers upon which they grow well. Contrasted with this is the defensive strategy developed by plants of long-persisting communities. For example, in an oak forest, chemicals such as tannins, resins, or terpenes that deter insects often are made in relatively large quantities. These substances cannot be combated effectively by insects. They tend to have a dosage-response effect on insect growth, slowing it down in a quantitative way: the more tannin, the slower the herbivore's growth.

The patchy and relatively ephemeral nature of the annual-plant populations of recently disturbed areas makes it more difficult for many kinds of herbivorous insects to find and exploit these plants as a food source. Under these circumstances the "qualitative" chemical defenses, imposing less of a metabolic cost, suffice to protect the plants from excessive defoliation. The established canopy trees, on the other hand, persist for long periods of time. As they are readily available to a great variety of insect herbivores, they must protect themselves by the metabolically costly production of large amounts of toxins, with which very few insect species can cope.

Alaskan Taiga Ecosystem

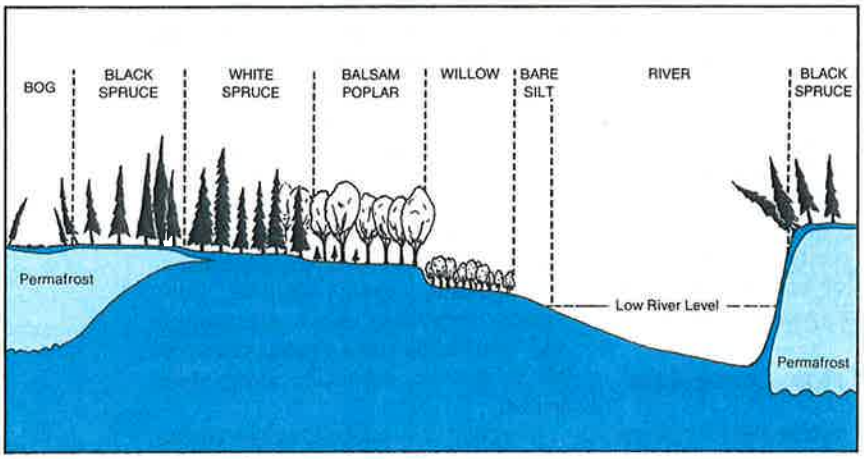
Unlike the community ecologist, the ecosystem ecologist studies the structure and dynamics of major distinctive elements of the world's biotic landscape. U.S. scientists were the pioneers in studying large-scale biomes. Under the auspices of the International Biological Program (IBP), the western grasslands and deserts, the eastern deciduous forests, and the western coniferous forests were the subject of integrated studies.

A significant post-IBP biome study examining the taiga, or subarctic forest, in Alaska is under way. This forest characteristically is dominated by spruce, variously mixed with deciduous trees and shrubs. On well drained sites and southern slopes, white spruce *(Picea glauca)* dominates a closed canopy forest while a sparse open forest dominated by black spruce *(Picea mariana)* occupies the extensive poorly drained areas, sites underlain by permafrost, and the cool, north-facing slopes. Black spruce-taiga extends to the limits of tree growth, both in the high altitude mountains and to the north where it is replaced by ground-hugging tundra vegetation. Of the 140 million hectares in the Alaskan interior, about one-quarter is covered by sparse open forest. Taiga, bog, and fen vegetation form the most widespread ground cover in interior Alaska.

The black spruce ecosystem appears to be the least productive forest type known. After a century of growth, a black spruce tree may be little taller than a person. Individual needles may be retained 25 years, and the older trees retain their dead branches arrayed on the bole beneath the small crown of living branches. This dry, "standing dead" material makes the black spruce ecosystem particularly susceptible to forest fires. In addition, their shallow root system, extending above the mineral soil, makes the trees readily susceptible to erosion, especially along river banks.

Frequent fires and the action of the abundant glacier-fed, silt-laden rivers continuously modify the landscape and topography of Alaska's vast interior basin. The plants that become established on newly deposited riverbanks belong to species different from those that become reestablished on burned areas. For instance, willow and poplar are among the pioneer species that grow on newly formed riverbanks, while black spruce and other plants become reestablished on burned sites. This study of the black spruce-taiga ecosystem, under the direction of Keith Van Cleve, University of Alaska, and Ted Dyrness, U.S. Forest Service, is aimed at understanding growth, succession, and the dynamics of nutrient-cycling in this ecosystem. The study is being conducted on lands controlled in part by the Bureau of Land Management. Additional long-term data are being supplied by the U.S. Forest Service, which also is contributing investigators and equipment.

The slow growth rate of the black spruce reflects the influence of low soil temperature and high soil moisture content on the rates of organic matter mineralization and nutrient cycling. But even the slow growing black spruce trees seem to further depress the already marginal ecosystem productivity. The protection provided by these trees permits the growth of a thick mat of feather-



Taiga ecosystem. A typical succession of plant species in the sparse taiga forests of Alaska begins with willows and poplars on newly formed silty riverbanks and progresses, as the community ages and the silt builds up above flood levels, to spruce. Growth of ground mosses under the protection of the spruce eventually retards the tree growth by sequestering nutrients and by promoting shallower permafrost. Frequent fires that burn off the mosses and older trees can rejuvenate the spruce forest. Current studies should be helpful in developing land management approaches.

mosses over the litter-strewn soil. The results to date indicate that the development of this moss mat further retards the growth of the black spruce in two ways. First, the mosses compete with the spruce roots for the nutrients released by mineralization of fallen organic matter. Second, the moss mat acts as a feather quilt, insulating the soil from warming during the brief hot summer and thus retarding mineralization. As the mat thickens, the permafrost surface gradually approaches the upper layer of the mineral soil and further retards tree growth. The study team believes that periodic burning of moribund trees and the feather-moss layer may provide the only escape from this tree strangulation. If burning occurs when the pine cones of the black spruce are closed, the cones tend to resist burning, thus protecting the seeds for dispersion later. The resultant seedlings bring a cycle of revegetation. By examining succession and ecosystem dynamics, the study should provide basic information that will prove useful in designing applied projects and in guiding land management practices.

Social Sciences

Human social institutions are variable and complex, and they change constantly in response to shifting circumstances. The study of social institutions thus presents a demanding challenge for scientific inquiry—to discern basic patterns of human social organization, to determine the general principles that explain how social institutions change and affect each other, and to describe the impact of changing institutional arrangements on the quality of human life and the achievement of social goals. Social science knowledge contributes to our comprehension of what is happening as social change intrudes to disrupt familiar routine. Such knowledge also provides the basis for enlightened public policies that will affect the well-being of our own and future generations.

The scientific study of social institutions is characterized by several distinctive features: (1) the search for general patterns and principles that extend beyond the particulars of a given time and place, (2) the dependence on reliable and reproducible data describing social institutions and their functioning, and (3) the systematic test of general principles against reliable data.

In contemporary social science, general principles may be expressed in many ways, such as in the form of mathematical models or verbal statements of comparison. They also may be formulated to pertain to relatively large human groupings such as nations, complex organizations, or communities—or to the relations between individual persons and the effect of the social context on individual response. Recognizing the uneven development of various social science subfields and the potential interplay between principles that pertain to individual interrelations and larger aggregates, NSF gives priority to studies that promise to contribute to the systematic development of abstract principles that can serve as general guides for understanding basic processes of social life and institutional change.

Reliable and useful social science data require the painstaking efforts of individual investigators and, frequently, of relatively large and highly organized teams of workers. The lack of adequate descriptive data continues to be a major impediment to the accelerated development of the social science disciplines. In response to this condition, NSF supports the

development of broadly useful data resources which can be made available to the general social science community. This support is most clearly illustrated in the development of social indicators designed to reflect trends and differentials in the quality of life and thus to help explore how major institutional changes affect the well-being of individual citizens. Other social science programs also are working toward the production and distribution of data resources and toward the improvement of data collection techniques. These developments are expected to enhance the capabilities of future social science research to contribute effectively to the development of more adequate and comprehensive social scientific findings.

The systematic testing of general formulations against relevant data constitutes the most demanding, the most exciting, and frequently the most visibly fruitful aspect of social sciences research. Such work builds on the development of models and principles worthy of extensive testing. It also requires methodological developments that permit assembling appropriate data and assessing the correspondence between the implications of the formulation being tested and the outcomes in the data being analyzed. In some areas of social science investigation, the necessary groundwork in building models and assessing data resources has not been completed. Current work, therefore, is concentrated on exploratory investigations, methodological developments, and the development of data resources. In other areas of investigation, models have been developed, and appropriate but imperfect data can be assembled to test their implications. This kind of work is most highly developed in economics, where functional econometric models operate on many levels (local, regional, national, and international) and concern many topics, such as housing, education, and the financial markets. Such models are becoming increasingly common in other social science disciplines too.

In some areas of social science, the accumulated knowledge base is not sufficient to permit the formulation and testing of multivariate explanatory models. Here, work may be supported not because it represents the culmination of work that has led to a profound understanding of social phenomena but because it represents the early stages in that effort—exploratory and descriptive work in new areas of investigation, methodological developments that promise to enhance the quality of future substantive work, or examinations of the tenability of tentative and relatively crude generalizations.

Foreign Policy Decision Analysis

Complex international negotiations often entail anticipations by each party concerning future decisions by the other parties involved. It is, therefore, of considerable importance to determine the major factors that influence foreign policy decisions. Of particular interest is the degree to which, and the conditions under which, decisions are shaped by the personal style of political leaders, by bureaucratic habits that are resistant to change, or by economic interests. These are among the factors being explored as determinants of foreign policy decisions in a series of studies based on a carefully coded data file of foreign policy events of 36 nations during the period 1959-68.

One of these studies, the Comparative Research on Events of Nations (CREON) project, is a multiuniversity research venture directed by principal investigator Charles Hermann of Ohio State University, Maurice A. East of the University of Kentucky, and Stephen A. Salmore of Rutgers, The State University. Their detailed data file draws together information from diverse sources, including content analyses of the responses of heads of state at press conferences during the period covered. The file contains a variety of information such as the personal characteristics of political leaders, structures and standard operating procedures of defense and foreign offices, constitutional characteristics of political regimes, social, economic, and political attributes of the nations, the structure of regional political systems, the past behavior of the nations in the conduct of their foreign policies, and transitory situations and events surrounding each identified foreign policy decision.

The investigators have been able to explore the degree of association between potential predictors of foreign policy and the actual outcome, and to assess the relative weight of particular factors under various conditions. On the basis of their analysis, they report that most foreign policy decisions are made within narrowly constricting bureaucratic constraints of the defense and foreign offices. Only under conditions of great crisis are the leaders relatively free from the constraints of organizational routines and short-term interests.

Through content analysis of the remarks of the leaders, the researchers were able to characterize the decisionmakers according to various personality traits. Under crisis conditions, particular facets of the leaders' personalities—for instance, their "need for power," internal self-control, distrust of others, or beliefs about the nature of man and the political order—played a dominant role in influencing foreign policy decisions. Foreign policy decisions made in noncrisis situations, on the other hand, were more closely related to the constraints imposed by past decisions, bureaucratic and political procedures, and national economic interests.

The data file for this project lends itself to a variety of exploratory

analyses, and those working on the CREON project already have published a number of them. Currently they are integrating these analyses into a coherent theory of foreign policy decisionmaking. This is one of several currently funded projects designed to increase understanding of factors related to foreign policy decisions. For example, Ole Holsti of Duke University and Alexander George of Stanford University are investigating the influence of decisionmakers' basic beliefs about political issues on their foreign policy decisions. Robert Axelrod of the University of Michigan is examining the processes by which participants in small groups having different beliefs and values reach political decisions.

Studies such as these promise to extend our understanding of how decisionmakers resolve difficult and complex issues. Although the factors that influence such decisions remain incompletely conceptualized and the nature of their influence under different conditions is not yet well understood, there is a growing accumulation of findings to illuminate how political leaders resolve conflicting influences in making decisions on matters of vital concern.

How American Adults Allocate Their Time

How people allocate their time is a fundamental area of measurement in social indicators research, because it directly reflects many aspects of life quality. Since 1974, the Foundation has been supporting a major national survey of time-use among American families. The survey is a project of the University of Michigan's Institute for Social Research, which conducted the first comprehensive time-budget study in the United States just 10 years ago.

Although basically a replication of the 1965-66 study, the present survey has been planned to produce data useful to another NSF-supported project dealing with the feasibility of extending national income accounting to include productive activities occurring outside the marketplace. Particular attention is being given to unpaid productive activities in order to arrive at a more realistic system of economic accounts and, in particular, to improve our understanding of the household as the Nation's basic economic unit.

The survey also has been planned to serve the needs of those Federal agencies concerned with such matters as income security and unemployment. Moreover, it is expected that an even wider range of Government and private organizations will find the results highly useful for policy analysis in such areas as transportation, health, the mass media, housework, childcare, and volunteer activities.

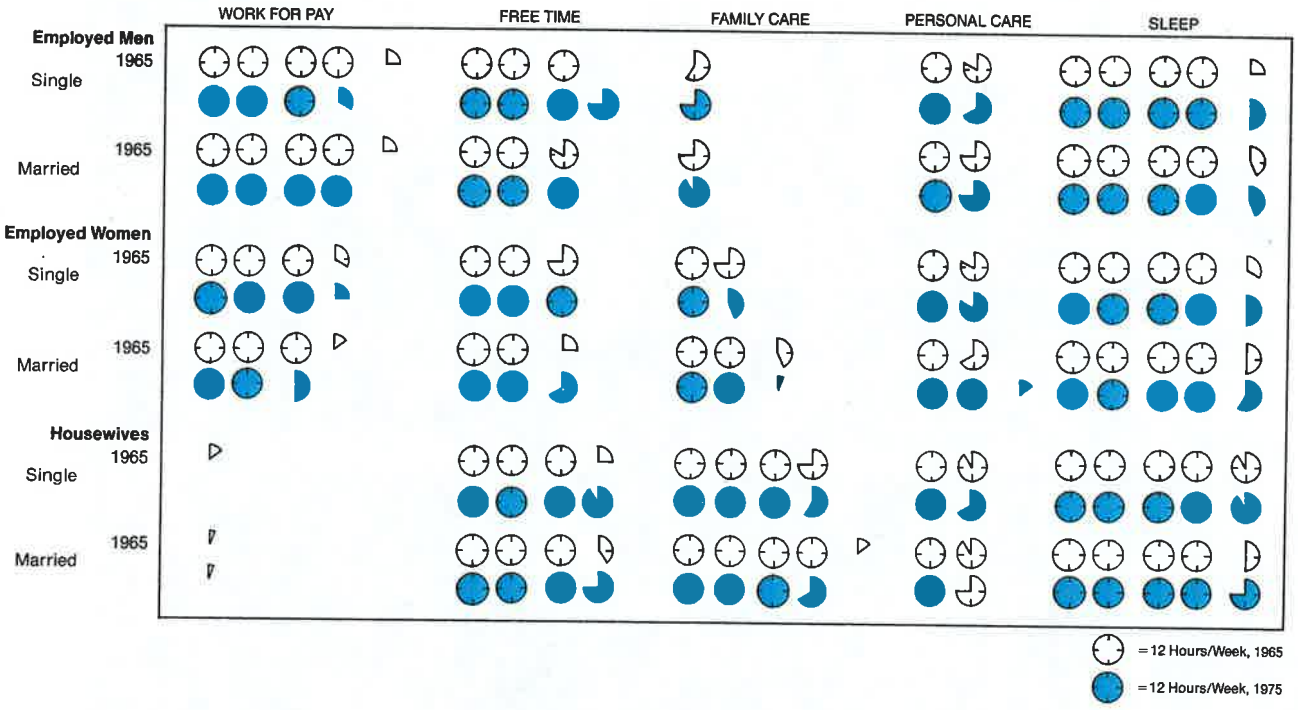
The present survey introduces several methodological innovations that make it the most sophisticated research of its kind. The types of analytic results anticipated from the research thus will go beyond currently available information on time-use. For example, considerable effort is devoted to developing an accounting system to differentiate use of time as "output" (valuable at the wage rate) versus time as "input" (pure consumption). If a quantitative assessment of this problem can be achieved, answers may be obtained to questions such as: What economic value can we attach to housework? How much do leisure activities contribute to work performance or accomplishments? How will new household technologies, like microwave ovens or cable TV, affect the way time is spent?

Although survey procedures are still in the final stage of completion, it is possible to present some preliminary results which compare estimates of time allocation from the early phases of the present survey with those obtained 10 years ago. A detailed exposition of differences in weekly hours devoted to various activities is scheduled to appear in *Social Indicators 1976*, a publication currently being prepared by the Office of Management and Budget.

Work for Pay. On an average, Americans spent less time working (including commuting) in 1975 than they did in 1965. This is true for both men and women. Although college graduates and the 24-45 age group increased their work hours, the rest of the population worked less. (This shift refers only to the employed segment of the population and is not affected by the higher unemployment rates of 1975.)

Family Care. Time spent on family care activities (mainly housework) has fallen almost 20 percent. As was true in 1965, most of the family care activity falls to women whether or not they work outside the home. Again in 1975 no difference has been found in the amount of housework done by married men whether or not their wives had outside employment.

Free Time. With less time being spent on work and family care in 1975, it is not surprising to find that Americans had more free time in 1975 than in 1965. The difference is significant, totaling almost 5 hours per week. The most dramatic rise in free time is registered by employed women, whose total free time in 1975 almost matched that of employed men. Among the working population in both 1965 and 1975, there is a curvilinear relationship between age and free time, the youngest (aged 18-25) and the oldest (aged 56-65) having the most of it. Older people registered a large drop in social life and in visiting friends and relations between 1965 and 1975. The level of education, which was unrelated to social life in 1965, now seems to be related to it in a positive direction. In other words, 10 years ago people engaged equally in social activities, regardless of how much education they had. Now, those with higher

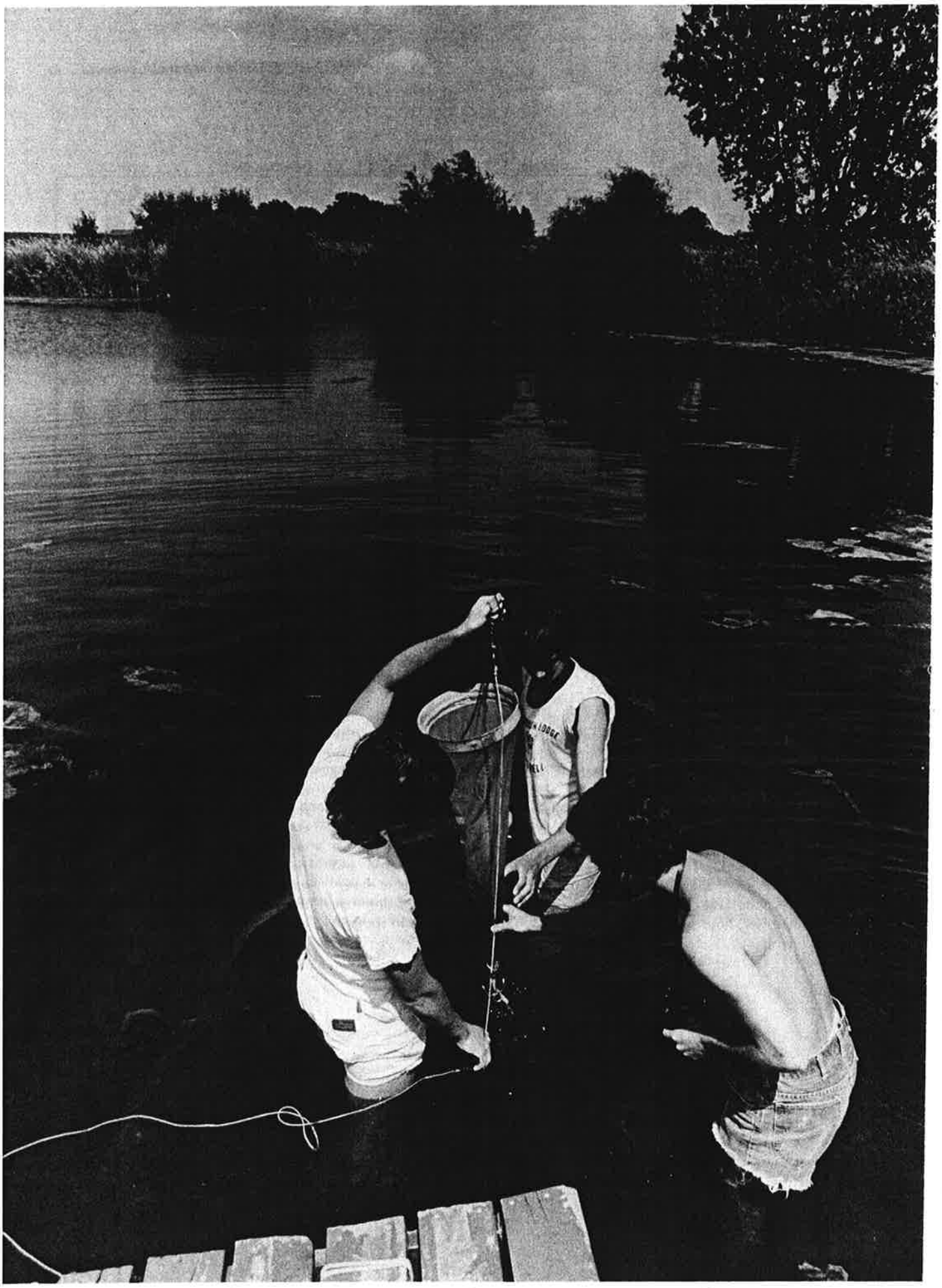


Spending time. These early, preliminary results of a major national survey of how adults allocate their time suggest significant shifts in relative amounts of time spent on work and free time over a 10-year span.

education tend to engage more in social life than those with less education.

Mass Media. Time spent watching television appears to have increased. Reading time has stayed about the same as in 1965, but time spent listening to radio and watching movies has declined. The major increase in television viewing was among women, who also showed the main decrease in housework and visiting. In 1965 there was an educational gap in media use—the more educated tended to watch less television than the less educated. By 1975 this gap had closed; only the college graduate group reported less media use than other groups in 1975.

It must be stressed that the above findings are only preliminary and represent a first crude cut at determining the general shape of time-use information in comparison to roughly similar information collected 10 years ago. The major analytic work is still to be done, and the data will become more interpretable as they are entered into social accounting frameworks and are mapped against significant social events of the past 10 years—such as the energy crisis, the rise of "counter-cultures," and the various political, economic, and social movements aimed at creating greater equity in our society.



Science Education

4

The goal of NSF's Science Education program is to initiate and support activities to strengthen education in the sciences at all levels. During the past year, the Foundation subjected this goal and the means by which it can be achieved to close scrutiny. As a result of this critical examination, the program has been restructured into the following four coherent areas:

Science manpower improvement, whose objectives are to identify and encourage scientific talent; to assist in the maintenance of high standards and quality in the training of students and professionals in the sciences; and to stimulate more participation in the sciences by minorities, women, and the handicapped.

Science education resources improvement, whose objective is to strengthen and improve the quality of science instruction and research training in schools, colleges, and universities.

Science education development and research, whose objectives are to advance our knowledge of how scientific concepts, processes, and skills are learned and to encourage the development of means by which the learning processes in science can be improved.

Science and society, whose objective is to bring about greater understanding of science and technology as it affects contemporary life, including the social and ethical implications and consequences of an increasingly technology-dependent society.

A factor in this realignment of programs was a series of Congressional actions that affected the science education program area. The first of these was the termination of the institutional grants for science program; the second was the establishment of two new programs designed to improve science education; and the third was the establishment of a new program designed to help citizens use scientific and technical information in order to deal more effectively with issues of public policy. In shaping the new programs, NSF has solicited the opinions of science educators and interested citizens through a series of regional meetings. This is part of a broader effort to identify and address national needs in science education.

Science Manpower Improvement

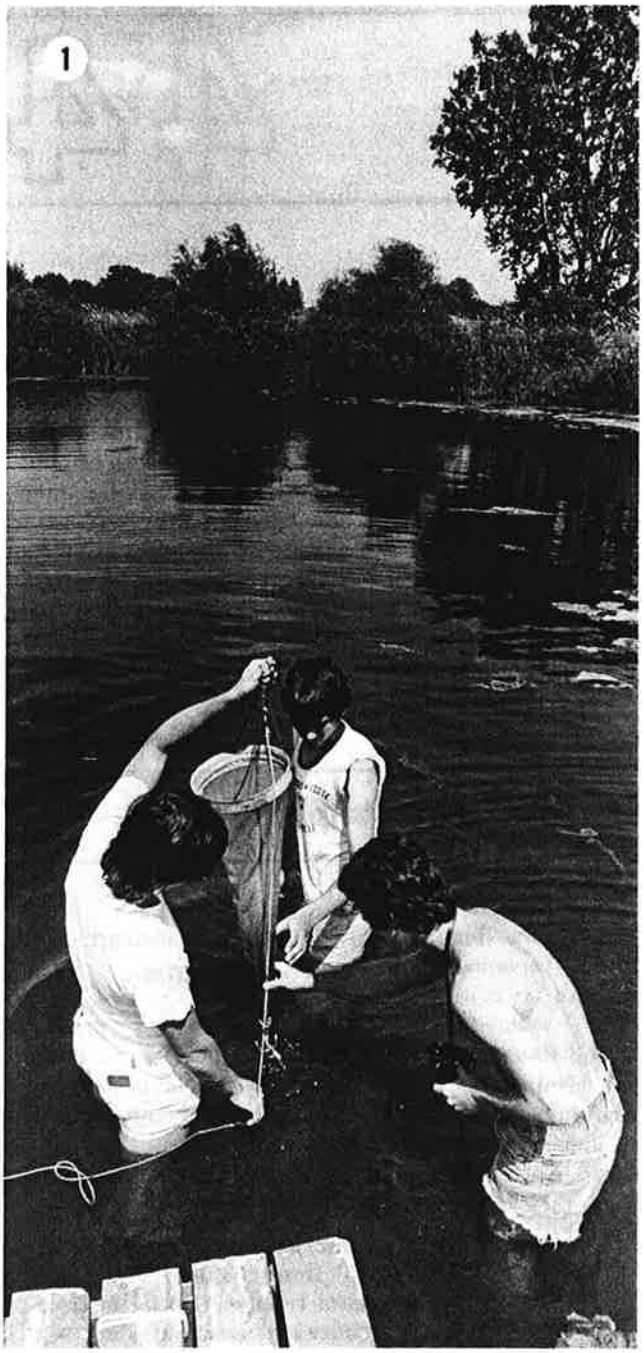
Programs that support the improvement of scientific personnel provide the Nation with a more effective supply of scientific manpower—a central and traditional responsibility of the Foundation. Student-oriented programs provide high school and undergraduate students with experience in scientific activities to encourage their entry into scientific careers. At the graduate and postdoctoral levels, the emphasis is on training highly talented young scientists, particularly training for research and teaching in scientific areas related to national needs. Faculty-oriented programs are designed to enhance the competence of teachers so as to maintain high quality in the training of students and professionals in the sciences.

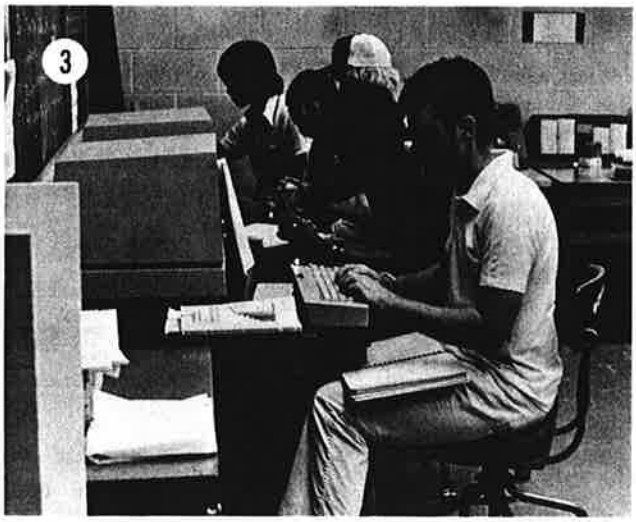
Student-Oriented Programs

The student-oriented programs encourage students of special interest and ability by providing challenges and opportunities not usually available at their level.

Student Science Training

In the 125 projects supported in 1976, some 4,400 high school students received special instruction in science and participated in research projects at colleges or universities. Fifty-two of these projects involved high-ability secondary school students whose opportunities have been limited by the facilities and instruction available in their own high schools.





Student Science Training. High school students take advantage of intensive science instruction opportunities at four colleges: (1) environmental biology of a pond at Wartburg College in Iowa; (2) math, probability, and computer language at Alabama State University; (3) computer processing of physics and astronomy data at East Carolina University; (4) oceanographic sample analysis at the University of Rhode Island.

Table 5
Science Manpower Improvement
Fiscal Year 1976 and Transition Quarter (July 1-Sept. 30, 1976)

	Fiscal Year 1976					Transition Quarter	
	Proposals		Awards		Number of Individuals Supported	Awards	
	Number	Amount	Number	Amount		Number	Amount
Fellowships and Traineeships	7,492	$ 78,797,704	776	$16,250,523	850	11	$527,748
Graduate Fellowships in Science and Engineering	6,419	53,100,000	550	11,372,685	550	11	527,748
Faculty Fellowships in Science Applied to Societal Problems	538	8,504,704	79	1,299,960	79	—0—	—0—
Energy-Related Postdoctoral Fellowships	455	5,454,000	118	1,414,336	118	—0—	—0—
Energy-Related Graduate Traineeships	80	11,739,000	29	2,163,542	103	—0—	—0—
Student-Oriented Programs	1,391	23,408,735	395	5,471,033	6,467	1	5,595
Student Science Training	320	6,960,580	125	1,944,957	4,400	1	5,595
Undergraduate Research Participation	627	9,664,335	201	2,543,770	1,481	—0—	—0—
Student-Originated Studies	444	6,783,820	69	982,306	586	—0—	—0—
Women in Science	144	5,128,575	33	1,003,431	6,350	1	1,266
Faculty Programs	235	3,351,932	116	2,157,150	3,552	—0—	—0—
Faculty Short Courses	13	913,392	13	894,450	3,325	—0—	—0—
Faculty Research Participation	222	2,438,540	103	1,262,700	227	—0—	—0—
Total	9,262	$110,686,946	1,320	$24,882,137	17,219	13	$534,609

Undergraduate Research Participation

This program provides opportunities to undergraduate students, who have completed a substantial portion of their science requirements, for full-time work with college faculty on research projects, an opportunity that goes beyond what is normally available in the curricula of the Nation's colleges. In 1976, among the 201 projects at 165 colleges and universities for 1,481 undergraduates were 3 designed to acquaint students with the research activities of industrial laboratories.

Student-Originated Studies

To encourage students to assume more responsibility for their own learning and to stimulate their interest in science, this program supports research activities conceived and carried out by the undergraduate students themselves with only minimal faculty supervision. In 1976, 69 awards supported the work of 586 students at 63 colleges and universities. Most of the projects were aimed at providing data relevant to the planning or administering of public programs.

Women In Science

In fiscal year 1976, the first year of full operation for this program, NSF supported 22 science career workshops in 17 States and 11 science career facilitation projects in 10 States and the District of Columbia. About 6,000 women participated in the workshops, which provide women students with candid information about career opportunities in various fields of science and various sectors of the economy. The facilitation projects helped about 350 women who received a bachelor's or master's degree between 2 and 15 years ago and needed a short, specially designed educational experience to enter or reenter employment or graduate degree programs in their fields of science. The projects supported were in fields of science judged to have greater than usual underrepresentation of women and good opportunities for employment.

Graduate and Postdoctoral Programs

Fellowships and traineeships for graduate study and for work in high-priority national needs areas increase the quality of scientific manpower and strengthen the scientific programs at the host institutions. These awards support the highest quality scientific talent available at the graduate and postdoctoral levels and strengthen the energy-related science capacity of the Nation.

Graduate Fellowships

New 3-year Graduate Fellowships were awarded in fiscal year 1976 to 550 beginning graduate students in science, mathematics, and engineering. This program is the only sizeable one—Federal or otherwise—spanning the sciences in which the fellows are selected in a national competition according to ability. Because only about one of every 11 applicants can be selected for an award, these fellows represent the most promising graduates of our colleges. In addition to the 550 fellows, almost 2,000 additional highly qualified applicants were accorded honorable mention, an identification that assists many of them in obtaining alternative awards without which they would be unable to undertake graduate study.

Energy-Related Graduate Traineeships

To help meet the Nation's emerging needs for scientific and professional manpower trained in energy-related areas, 29 grants were made to 26 institutions in support of the energy-related training and research of 103 graduate students.

Each traineeship provides for 3 years of work in one of two research areas: coal or nonrenewable resources (such as extractive metallurgy, geothermal reservoirs, explorative geophysics, geochemistry of hydrothermal uranium deposits, and tertiary oil recovery).

Energy-Related Postdoctoral Fellowships

Fellowship awards were made to 118 young scientists demonstrating special aptitude for study and research on energy-related problems. The fellows receive stipends in support of up to a year of research and training to increase their competence in research and instruction in energy-related areas.

Faculty-Oriented Programs

These programs, which enhance the professional skills of science teachers, improve both process and content of science instruction for all students.

College Faculty Short Courses

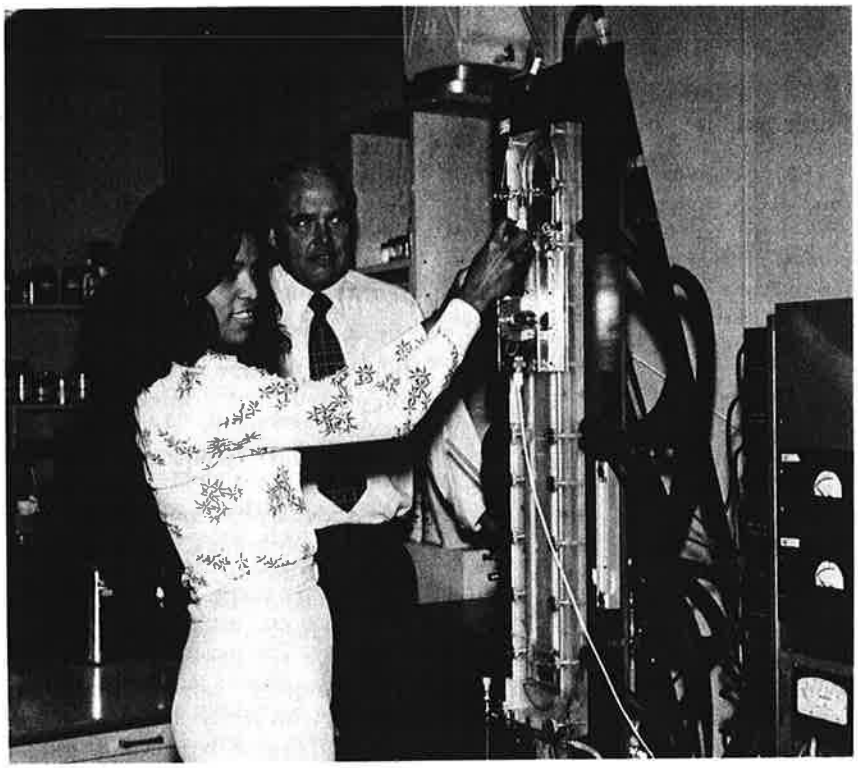
This program to expose faculty to new scientific knowledge and expedite its dissemination in the classroom is of particular value to faculty from 2- and 4-year colleges without active campus research programs. Forty-five different short courses were offered in 127 classes held at 13 field centers across the Nation. Approximately 3,200 college teachers attended these short, intensive presentations by experts. Also in fiscal year 1976, 150 high school science teachers attended three courses offered as a trial-run of the feasibility of this format for secondary school teachers. The program has involved teachers from all of the 50 States and Puerto Rico, representing one-half to two-thirds of all the institutions of higher education in the Nation.

Faculty Fellowships in Science Applied to Societal Problems

These fellowships, awarded to 79 experienced teachers in 2- and 4-year colleges and universities, enabled them to undertake independent study and research to increase their competence in areas specifically related to the Nation's problems and their possible solutions. The fellows, from 69 colleges and universities in 31 States, conducted their projects for periods ranging from 3 to 9 months at institutions appropriate to the topic of the projects. The topics ranged from the development of physics courses for students in health-related fields to an improved understanding of criminal behavior and violence.

Faculty Research Participation

This program assists college teachers in reevaluating the relevance of their course materials to the needs and requirements of students. To help do this, science faculty participate in the ongoing research activities of industrial laboratories and research institutes. In its 3 years of operation, the program supported the participation of over 500 college teachers in such applied research experiences. The projects in 1976 included research on energy conversion and recovery, pollutants, biomedical products and systems, computer control of industrial processing, exploitation and development of materials, and electronic devices for communication, diagnosis, and processing.



Faculty Research Participation. Marion Johnson, a faculty member at Federal City College in Washington, D.C., participates in a project to separate and purify biological materials with Louis McCreight at General Electric's Space Science Laboratory.

Science Education Resources Improvement

The primary objective of NSF's science education resources improvement programs is to strengthen and improve the science education and research training capabilities of schools, colleges, and universities. These programs support equipment purchase, research, course improvement, and comprehensive multidisciplinary programs in science education. The regional meetings held in early fiscal year 1976 during the development of the two newest programs—Research Initiation and Support, and Comprehensive Assistance to Undergraduate Science Education—contributed significantly to their initial success by allowing the Foundation to focus on the realistic needs of the science education community. Those who attended the meetings also indicated their commitment to support for these programs by volunteering to serve on review panels.

Research Initiation and Support

The Research Initiation and Support (RIAS) program was established by the Congress on August 9, 1975, to provide assistance to institutions of higher learning in their efforts to improve the quality, effectiveness, and efficiency of their graduate and postgraduate programs for young scientists and engineers. For the purposes of this program, "young scientists and engineers" are defined as graduate students, postdoctoral appointees, or nontenured faculty members who have earned their highest postgraduate degree during the past 5 years.

To help shape the program and to give it visibility, 761 U.S. institutions offering graduate programs in science were invited to send representatives to six regional meetings held in October of 1975 in Chicago, Houston, Denver, Los Angeles, and Washington (two meetings). The 394 attendees provided extensive comments on and reactions to a draft of the RIAS guidelines, which had been mailed to them before the meetings. These suggestions received careful consideration in the formulation of the final RIAS guidelines.

A total of 261 proposals requesting some $59 million was submitted for the Foundation's consideration by the program's March 15 closing date. Results of the competition were announced on June 23, 1976, with $4.0 million being awarded to 19 institutions. Of the grantees, six were so-called research universities; five were other doctorate-granting institutions; six were institutions whose graduate training is conducted, for the most part, at the master's level; and two were consortia.

Projects supported differ widely in their complexity and organization. Some institutions have tried to address their training and research needs at the departmental or interdepartmental level. At Brown University, for example, the Geological Sciences Department and the Engineering Division are pooling their resources to strengthen an emerging interdisciplinary program in tectonophysics, which deals with the physics of deformation in the Earth.

Other colleges and universities, on the other hand, have approached the problem in an institution-wide mode. Typical of this approach is a program at Iowa State University to improve the training of young scientists in the effective use of new digital information techniques for experimental control, data acquisition, large data-based manipulation, and specialized computation. By drawing together elements and strengths existing in the Departments of Electrical Engineering and Computer Science and the University Computation Center, Iowa State will provide advanced training and services in computation to young scientists from four colleges and 20 departments.

Two of the awards were made to institutions acting in consort. One such grant provides support for a joint doctoral program in plant biology conducted by Lehman College of the City University of New York and the New York Botanical Garden. The program enriches the research

Table 6
Science Education Resources Improvement
Fiscal Year 1976 and Transition Quarter (July 1-Sept. 30, 1976)

	Fiscal Year 1976				Transition Quarter	
	Awards		Awards		Awards	
	Number	Amount	Number	Amount	Number	Amount
Comprehensive Assistance to Undergraduate Science Education	760	$151,354,040	59	$10,111,733	.1	$ 33,858
Minority Institutions Science Improvement	60	16,981,548	26	4,742,521	1	1,515
Local Course Improvement	192	4,125,471	73	1,032,476	—0—	—0—
Instructional Equipment	1,649	18,137,196	329	2,993,456	—0—	—0—
Improvement of Pre-College Instruction	29	2,949,797	3	1,435,150	3	285,230
Research Initiation and Support	261	59,319,779	19	4,008,996	—0—	—0—
Total	2,951	$252,867,831	509	$24,324,332	5	$320,603

and training opportunities available to young scientists at Lehman by providing modern laboratory facilities that will allow them to take fuller advantage of the outstanding resources of the Botanical Garden.

Improvement of Pre-College Instruction

The primary purpose of this program is to improve elementary and secondary school science education by providing support for the development of models for more effective pre-service and in-service teacher education.

In the area of pre-service teacher education in 1976, the Foundation concentrated its support on the assessment of the impact of previously developed models rather than on the development of additional new models. Two such awards were made this past year. Also, the Navajo Division of Education received a planning award directed toward increasing the number of Navajo teachers of science and mathematics.

As a way to encourage a coordinated attack on complex problems involving State, regional, or urban systems of science education, the Foundation awards relatively large sums of money in a few large-scale projects that involve several strata in the educational structure. This year grants were made in further support of "Project City Science" in New York City's middle schools and the Oregon Mathematics Education project.

The Foundation is continuing its efforts to improve the teaching skills of practicing classroom teachers through the support of localized Teachers' Centers. Renewal grants were made to Teachers' Centers in California, Colorado, and Wisconsin. An ongoing third-party evaluation of these Centers is being conducted under Foundation support through the Department of Science Education at the University of Georgia.

Comprehensive Assistance to Undergraduate Science Education

CAUSE was established by legislation on August 9, 1975. Its major objective is to strengthen the science education capabilities of predominantly undergraduate educational institutions and departments or groups of departments. Awards are made for revitalizing or improving science education within 4-year colleges, 2-year colleges, groups of such institutions, and for the undergraduate components of advanced-degree institutions.

In the fall of 1975 the program held 13 regional conferences at which representatives from eligible institutions made suggestions to improve the draft guidelines. Final guidelines were issued in November 1975, with proposals due by February 16, 1976. On June 18, 1976, 59 awards were announced totaling $10.1 million; denial letters were sent for 701 proposals requesting $150 million.

It is too early to determine the success or impact of a given local project. On a national level, however, it is evident from fiscal year 1976 proposals that CAUSE must continue to address the needs of a variety of institutions—large and small, public and private—that have experienced a decline in undergraduate science education standards over the past decade. In supporting these improvements, particular attention will have to be given to a large number of institutions heretofore uninvolved in the science education activities of the Foundation. Congress mandated that 20 percent of CAUSE funds be awarded to 2-year colleges. In fiscal year 1976 the success ratios for 2-year and 4-year colleges were approximately equal.

CAUSE projects reflect each institution's unique efforts to improve undergraduate science education. Therefore, a majority of awards deal with several science disciplines representing the coordinated efforts of their science divisions or departments. Comprehensive educational strategies include varying degrees of course revision, development of audio-tutorial activities, use of computer technology, improvement of field or classroom instructional facilities, staff training, or purchase of related instructional equipment. For example, the College of Idaho will incorporate modern computing facilities within the course work of undergraduate science classrooms. The project calls for the purchase of a minicomputer and requisite training of science faculty in the use of computers. At Mohave Community College, funds will be used to purchase two mobile science vans needed to serve undergraduate students in remote regions. Additional funds will be provided for specific instructional equipment and for the development of expanded course offerings in the physical and biological sciences.

Educational Program Restructuring

The primary purposes of educational program restructuring are to encourage the development, testing, and evaluation of new or unconventional approaches to all aspects of science instruction at the undergraduate level, and to produce changes in the undergraduate science learning experiences of science majors, nonscience majors enrolled in science courses, or those preparing specifically for careers as teachers of elementary and secondary school science.

In fiscal year 1976 this program completed its evolution from support of massive institutional restructuring projects to highly focused projects for restructuring of local course content or method of delivery. Awards ranging from $2,700 to $25,000 went to 69 colleges and universities in support of innovative science teaching

projects designed by individual or small groups of science faculty members.

At the State University of New York in Binghamton, undergraduate science majors will gain experience in communicating scientific knowledge to the lay public while they are still preparing themselves for scientific careers. The project involves an interdisciplinary collaboration among the several science departments, the English Department, and the Educational Communications Department.

The chemistry faculty at Xavier University of Louisiana will develop learning modules for use in two general chemistry laboratory courses and will conduct a pilot study of their effectiveness. At Hillsborough Community College in Tampa, Florida, computer programs will be developed for student use to stimulate basic physical concepts and to permit mathematical modeling of physical processes or systems. And at the University of the Pacific, in Stockton, Calif., a multidisciplinary, upper-division, natural science laboratory course will be designed expressly for science majors. The course will make students aware of the interrelationships between scientific disciplines and teach them the value of skills and methods of disciplines other than the students' own majors.

Instructional Scientific Equipment Program

This program continues to provide small grants to both 2- and 4-year colleges and universities as matching funds to support scientific and/or instructional equipment purchases needed to implement specific science course and curriculum revisions. In fiscal year 1976 the program made 329 awards, averaging $8,930, to 277 institutions located in 49 States, the District of Columbia, and the Commonwealth of Puerto Rico.

The greatest numbers of proposals and resultant awards this year involved projects in the physical sciences, followed by the life sciences and engineering. The earth and social sciences were relatively as successful in the competition as the other sciences, but submitted fewer proposals.

Grants were made to support purchase of equipment ranging over minicomputers in engineering, seismic apparatus for use in geology, equipment to perform data manipulation in the social sciences, and analytical equipment for the life sciences. It is perhaps noteworthy that 65 percent of the funds to be expended for these projects will support the purchase of computational equipment for use in a variety of science instructional activities.

Minority Institutions Science Improvement

To help increase the flow of underrepresented ethnic minorities into science careers and to improve the quality of science education programs at minority institutions, NSF supports projects designed to effect long-range improvements in science education at institutions whose enrollments are predominantly Black, Native-American, Spanish-speaking, or other disadvantaged ethnic minorities. Approximately 200 2- and 4-year colleges and universities, which enroll more than 400,000 students, are eligible to participate in the program.

This fiscal year 85 awards were made by the minority institutions science improvement program and by the research initiation for minority institution improvement program. These included 26 multiyear institutional science improvement project awards, 6 regional briefing conference awards designed to inform newly eligible institutions of the programs, and 53 grants to individual science faculty members at 26 minority institutions for initiating scientific research.

Science Education Development and Research

The science education development and research programs assist in the improvement of teaching and learning through support for the development, evaluation, and use of innovative instructional technologies, teaching methods, and course materials to increase the quality, cost-effectiveness, and currentness of science education at all levels.

Several kinds of projects were supported during fiscal year 1976. A number of them involve the developing and testing of new materials for use in elementary and secondary school science courses. These materials help prepare students for more advanced work in scientific and technological fields and also provide science literacy for the much larger number of students who need a thorough understanding of science to function effectively in a technologically sophisticated society.

Other projects are intended to improve science education at the college level. Instructional materials were developed, innovative delivery modes were tested, and new curricula were designed to improve the capability of colleges and universities to educate scientists and engineers. Grants were also made to identify more effective ways to deliver continuing education to practicing scientists and engineers. Finally, several investigators are seeking to develop computer-based instructional systems

Table 7
Science Education Development and Research
Fiscal Year 1976 and Transition Quarter (July 1-Sept. 30, 1976)

	Fiscal Year 1976				Transition Quarter	
	Proposals		Awards		Awards	
	Number	Amount	Number	Amount	Number	Amount
Pre-College Materials Development, Testing and Evaluation	31	$ 9,156,167	26	$ 4,293,717	4	$1,328,080
Alternatives in Higher Education	57	14,398,383	16	2,486,818	6	333,271
Science and Engineering Technical Education	15	3,668,000	2	288,600	—0—	—0—
Continuing Education for Scientists and Engineers	8	1,817,039	2	221,146	—0—	—0—
Technological Innovation in Education	65	16,239,681	14	2,925,595	2	684,238
Special Studies and Experimental Projects	22	1,417,914	18	716,252	1	255,965
Total	**198**	**$46,697,184**	**78**	**$10,932,128**	**13**	**$2,601,554**

that ultimately can make individualized instruction available at costs that are competitive with conventional instructional systems.

Pre-College Materials Development, Testing, and Evaluation

Fiscal year 1976 was a time for intensive review and reevaluation of this program and its achievements and ongoing rationale. Following the solicitation of nominations from virtually every interested professional and civic organization in the Nation, 73 experts convened in Washington in December 1975 for a week's exhaustive study of the products of 19 Foundation-supported projects. They submitted extensive comments, criticisms, and recommendations. These reviews provided a basis for NSF's support for the continuation or completion of several projects. For example, Earle L. Lomon of Education Development Center received a grant to complete the development and classroom testing of instructional units that teach mathematics and science to elementary school children by engaging them in investigations into a variety of practical problems. A project at the University of Oregon, directed by Alan Hoffer, is developing in-service and instructional resource materials from which teachers of mathematics can select to extend their own knowledge and to increase the flexibility of the learning environment for their students. These materials, suitable for use at the middle-school level, treat such topics as "measurement and the metric system" and "relations and graphs."

A group led by Watson M. Laetsch of the Lawrence Hall of Science at the University of California, Berkeley, is designing instructional strategies for teaching biology through outdoor

Junior high science. Students in Los Angeles work on a unit of the widely used Intermediate Science Curriculum Study, a series of science courses developed with NSF support.

activities. The American Psychological Association received a grant to continue the development of a course on human behavior. The project staff, led by John Bare of Carleton College, is producing modular units for use in secondary school psychology courses. The Foundation is also supporting the development of a high school course in American government by the American Political Science Association in a project directed by Howard Mehlinger.

One newly funded project may prove to typify the more discrete targeting of funding that is expected to be the program's rule in the future. Increasing scholarly acceptance of the principles of plate tectonics has transformed the science of geology during the past decade, outdating virtually all teaching of earth science. Under the direction of the President of the National Association of Geology Teachers, Edward C. Stoever, Jr., University of Oklahoma, classroom teachers, researchers knowledgeable in crustal evolution, and support personnel at six college-based development centers will produce approximately 50 supplemental instructional units in areas where the impact of recent discoveries has changed what needs to be taught at introductory-level courses.

Also supported in 1976 was a further test of the thesis that science museums need not be staid nor musty, but function best when visitors "can integrate learning and enjoyment" as they ". . .share and feel at home with the cumulative and increasingly coherent awareness of nature that is the traditional harvest of scientists. . . ." Frank Oppenheimer, Director of the San Francisco-based Exploratorium since 1969, has sought to make discovering the museum "like stumbling into the belly of a giant whale where some mad scientist has found a home." A recent award will test his notion that science museums are most effective when they are places where people not only learn, but do so as they "participate—touch, pound, open, pull on, look through, listen to, screech at, and climb through" the exhibitions.

In addition, three contracts have been let to produce objective needs analyses in relevant aspects of pre-college science education. The awarding of major grants to develop new pre-college curricula has been suspended until these finding can be considered.

Alternatives in Higher Education

Projects in this category are designed to increase the educational options available to people who must use science and engineering in their work, as well as those who are going into academic or industrial science careers. In fiscal year 1976 the program continued to focus on the development of materials for experimental courses and for programs dealing with new areas of science; on new modes of delivering science instruction; on the development of alternatives to traditional science and engineering degree programs; and on the development of prototype programs for future technicians who will serve as assistants to scientists and engineers.

Updating of many college-level science courses is hampered by at least two factors: most college professors have insufficient time to work into their classroom presentations all the new materials and discoveries needed to keep their instruction current, and some are too overloaded or too remote from the professional mainstream even to keep abreast of all the highly specialized content their courses should include. Since virtually every decision as to what will be taught to a given college class is made by the professor who presides over that classroom, distribution systems for curricular materials must be designed with adequate attention to the structure of that system if they are to be effective.

This program, accordingly, is conducting several concurrent experiments to provide additional insights into what influences the choice of instructional materials in the scientific and engineering disciplines. Several new projects are illustrative of these experiments. Colin Moodie of Purdue University is developing and testing a variety of educational materials relevant to production engineering. The American Universities Field Staff has already produced 25 films tracing themes such as the role of women through different cultures. Now Norman Miller is directing the development and testing of essays designed to assist students enrolled in various college social science courses to derive maximum benefit from viewing the films. Finally, the Education Development Center is developing modular instructional units on topics in mathematics for use by science students. A major goal of the project, which will show the applications of mathematics to problems in the natural and social sciences, is to devise procedures through which such units can be generated, reviewed, catalogued, and retrieved for use by faculty members as part of their regular professional duties.

At the University of Illinois, Paul Handler and his colleagues are preparing instructional units on population and its effect on the social and economic well-being of the peoples of the world. These new units, along with specifications for the storage and retrieval of existing demographic data in a variety of computerized data banks, will make it possible for social and physical science instructors in other colleges and universities to incorporate up-to-date material on population-related issues into their courses. Also, the American Society for Microbiology is intensifying its efforts to improve and diversify the

array of teaching aids available to instructors of courses in microbiology.

Other projects are focusing on making improvements in the teaching process. John J. Allan, III, and J. J. Lagowski at the University of Texas at Austin are completing a 4-year study of the impact of computer-based instruction at a large university. Previous support had enabled instructors in many different disciplines to use interactive terminals, interactive graphics, laboratory data acquisition and process control, mark-sense grading, real-time video projection, and terminal-controlled video and slides in their courses. At the university of Chicago, William D. Pattison has been organizing teaching development programs for doctoral students in geography, and the Association for American Geographers has assumed responsibility for extending educational reform in the teaching of geography throughout the undergraduate and pre-college levels.

The alternatives in higher education program has also supported a number of projects aimed at generating new curricula. For example, the University of Michigan and Massachusetts Institute of Technology are cooperating in designing and testing a program for introducing the latest computer-aided methods of designing ships into their programs in naval architecture. Northwestern University is experimenting with a novel plan for providing undergraduate science students with enough balance in the major science disciplines to permit each candidate to select either graduate work in any one of several different fields or employment in an interdisciplinary area. Because this project, directed by Robert C. Speed, will admit only very able students, graduation after 3 years will be possible for some, even though the courses will be rigorous and thorough.

Science and Engineering Technician Education Program

Proposals to develop and test curricular programs for training technicians to contribute to research development in specific subfields of science and engineering were reviewed this past year by a panel of experts, which made several recommendations for awards. Typical of these is a project at Oklahoma State University for the development of a model program for the training of electrical technicians with special expertise in power engineering. A very different activity is being led by Robert Tinker of Springfield Technical Community College, which is developing improved materials for basic courses in physics and mathematics suitable for a wide range of prospective technicians.

Continuing Education for Scientists and Engineers

While no major new projects in the delivery of continuing education to scientists and engineers were initiated during 1976, several projects started the previous year continued their efforts. Typical of these is the work of Jack Munushian at the University of Southern California, where he and his colleagues have been developing materials for courses offered on closed-circuit television. The courses are available at off-campus sites conveniently located with respect to the aerospace industries where the intended engineering students are employed. An innovative feature of this system is the inclusion of opportunities for the students at their various remote locations to interact via an audio channel with the instructor on the campus while the lecture is in progress.

Technological Innovation in Education

During the past several years, support has been provided for several experimental computer-based systems of instruction. Fiscal year 1976 saw a phasing out of large-scale support for system development and the beginning of a greater emphasis on how the computer can be used to improve learning, the development of computer courseware, and investigations into the cost-effectiveness of computer-based instruction. Terminal grants were made to the University of Illinois in support of the PLATO system, to the Mitre Corporation to complete development of the TICCIT system, and to the Educational Testing Service for the evaluation of these systems.

Research into the role the computer can play in facilitating learning is being conducted by Seymour Papert at MIT. Papert teaches young children to program mechanical devices and computers to run mazes, draw diagrams, and solve problems, and then studies how these talents affect the students' motivation for further activities and the numerical and verbal skills they display in performing basic tasks. At the University of California, Irvine, Alfred Bork is developing instructional materials that exploit the graphical capabilities of a computer and testing them on relatively large numbers of students who are enrolled in various physics courses. Detailed records are kept of how many students use the materials, the times and circumstances characteristic of their uses, and the nature of assistance the students seek and receive. At Stanford University, Patrick Suppes is directing investigations into the use of the computer as a language processor. Included in this work are efforts to explore the potential of computer-generated speech and the possibility of teaching reading more effectively by combining audio materials and computer-assisted instruction techniques.

Science and Society

Several different activities were consolidated into a new science and society program in 1976 to provide a focus for issues arising out of the changing relationships between the scientific and technological communities and the society of which they are part. The increased specialization and institutionalization of science and technology and their pervasive influence on contemporary life have added to a growing concern about the ethical implications and social consequences of these activities. The problem of "accountability" has emerged as a central social issue affecting science no less than government, business, education, and our other major institutions. It is the distinctive task of the science and society program to try to bring about greater understanding of these changes and problems, both among the general public and within the scientific and technological communities themselves.

How do the activities of scientists affect our lives? How and by whom are decisions made about the direction of scientific activities and the resources invested in them, and how should these decisions be made in a democratic society? Against what ethical and social standards can and should they be judged? How can citizens who are not scientists participate effectively in public policy decisions with important scientific and technological components? Each of the programs approaches these difficult and perplexing questions in a different way.

Science for Citizens

Authorized by Congress in fiscal year 1976, the science for citizens program seeks:

- To facilitate the participation of scientists and nonscientists in the processes by which public policy issues with significant scientific and technological components are resolved.
- To enable citizens, individually and collectively, to identify and secure scientific and technical information that will enable them to deal more effectively with issues of public policy.
- To establish effective dialogues between citizens and scientists, especially at local and community levels, that will lead to increased mutual understanding.

Table 8
Science and Society
Fiscal Year 1976 and Transition Quarter (July 1-Sept. 30, 1976)

	Fiscal Year 1976				Transition Quarter	
	Proposals		Awards		Awards	
	Number	Amount	Number	Amount	Number	Amount
Science for Citizens[1]	—0—	—0—	—0—	—0—	—0—	—0—
Public Understanding of Science	84	$16,200,000	34	$1,671,326	1	$ 27,783
Ethical and Human Value Implications of Science and Technology	111	12,067,000	19	670,757	1	172,448
Total	195	$28,267,000	53	$2,342,083	2	$200,231

[1] In program development stage. No proposals received or awards made.

In response to the Congressional mandate to seek broad public participation in the development of the program, NSF sponsored seven regional forums in December 1975 prior to submitting a program plan to Congress. Over 1,400 persons contributed to the planning process, including private citizens and public officials; persons from business, industry, labor, and consulting firms; directors, staff, and volunteers in science museums and centers; and representatives of public interest groups and professional societies. The report to Congress offered nine program options.

Ethical and Human Value Implications of Science and Technology (EHVIST)

The ethical and human value implications of science and technology program was established in 1975 and deals with such questions as:

- The ethical problems and conflicts generated by scientific and technological developments, as they affect both the scientific community and the larger society.
- The impact of changing ethical and social standards on the scientific and technological enterprise, including the issues raised in establishing research priorities and in regulating the conduct of research.
- The ethical issues and problems that arise within science and technology, including those encountered by scientists and engineers in their professional capacities.
- The processes of interaction between science and society that generate value conflicts and those that may lead to their resolution.

In 1976 the program supported experimental institutes and workshops, national and international conferences and symposia, interdisciplinary research, and the preparation of reference materials. Several awards were made jointly by the EHVIST program and the National Endowment for the Humanities, including one to support an experimental institute on ethical theory for scientists and engineers interested in teaching and research on the subject, and another to support an interdisciplinary workshop to design an agenda for studying the relationship of American values to alternative types of human living environments. A number of awards went to studies of the ethical issues arising in particular cases of scientific research or out of particular forms of technological development. Some of these projects focus on environmental issues and others on the interactions between individual and social values and scientific and technological development. One project, for example, deals with the ethical questions surrounding the dismissal of three engineers employed by a rapid transit district who voiced their concern about the potential safety of the automatic train control system.

Fiscal year 1976 marks the second year of a project to collect and make accessible all printed and oral history materials on the development of the controversial recombinant DNA research guidelines and on the events that followed. The program also funded conferences, workshops, and symposia to begin the process of developing ethical guidelines for scientists in several fields, including those conducting research on human tissue cultures and on human reproductive biology (jointly funded with the National Institute of Mental Health). Computer scientists and psychologists at work in the criminal justice system will also be considering the development of ethical guidelines at workshops funded by the program in 1976.

Public Understanding of Science

This program directs its activities toward increasing public understanding of the social and intellectual processes underlying science and technology and of the scientific and technological components of public policy issues. The program supports projects that make use of a variety of communication channels including, for example, television and other mass media, museum exhibits, lectures, conferences, forums, and scien-

History of recombinant DNA guidelines. The MIT Technology Studies Program is compiling a collection of historical materials relating to the ongoing debate (such as this working session of scientists at the 1975 Asilomar Conference) over recombinant DNA research. (Photo by Andrew Stern for National Academy of Sciences.)

Saturday morning television. With NSF support, a series of science "Closeups" has been prepared for use on network television during children's shows. In each segment Mr. Wizard presents a very close view of some familiar science-related object. Children are challenged to guess the object while they are told a bit of the science background.

tific journalism and publication. Given the diversity of backgrounds, education, and interests of American citizens, some projects are aimed at special audiences, such as minority groups, rural populations, senior citizens, and union members. Recent projects include:

NOVA. This popular public television science program now reaches an audience estimated at four to seven million viewers each week. During the current season it presented programs on topics ranging from genetics and astronomy to energy and insecticides.

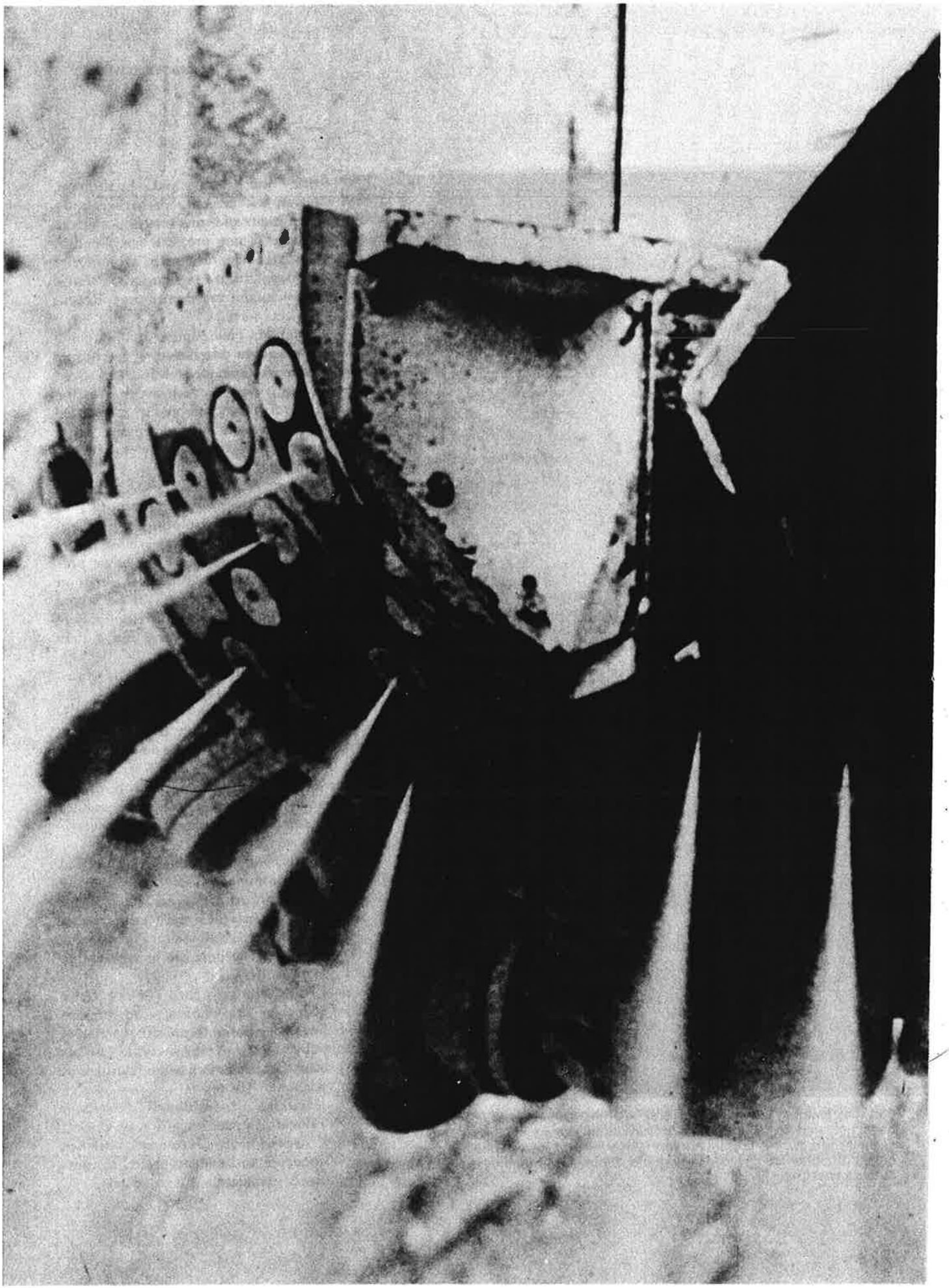
Science for local TV news. A group at the Massachusetts Institute of Technology is exploring a new approach to disseminating science information through local TV news programs. A series of brief films on world food problems will be tested this year; if successful, the project could become the basis for a new science news service.

Public awareness program. The country's largest scientific society, the American Association for the Advancement of Science, has begun a comprehensive program including regional seminars about science and technology, mass media internships and workshops to improve science reporting, and a science film reviewing service.

Astronomy in the parks. The American Astronomical Society and the National Park Service have begun a program in which park rangers and naturalists teach visitors about the stars and the universe as well as the local ecology and geology.

The Christmas Lectures. For the past 6 years, several Chicago universities have cooperated to present a series of public lectures by world famous scientists who discuss the frontiers of science in lay terms.

Science for children's television. Television's Mr. Wizard is producing a series of 30-second science segments to be incorporated in commercial children's TV programs.



Research Applied To National Needs

5

NSF established the Research Applied to National Needs (RANN) program in 1971 to bring the resources of science and technology to bear on selected important national problems. To do this, the RANN program acts to:

- Identify national needs that are not being addressed by existing research agencies, provide early warning of potential national problems, and initiate assessments and research that address these needs and problems.
- Increase the effective use of science and technology in dealing with national problems.
- Shorten the leadtime between basic scientific discoveries and relevant practical applications and serve as a bridge between the Foundation's basic research programs and the development, demonstration, and operational programs of Federal mission agencies, State and local governments, and industry.
- Assure the communication and use of the research results.

In furtherance of these goals, and reflecting changing national priorities, RANN reorganized its activities in fiscal year 1976 to focus on the following five major areas:

Resources—strategies and new technologies that will make possible more effective use of renewable and nonrenewable resources in the national interest.

Environment—enhancement of the Nation's capacity to mitigate environmental hazards, whether natural or manmade.

Productivity—policy research and development of new technologies to help improve the productivity of the public and private sectors of the economy.

Exploratory Research and Technology Assessment—research and assessment to provide better understanding of the long-range social, environmental, and economic impact of new technology applications, and to identify and analyze emerging national problems that may be avoided or ameliorated by effective application of science and technology.

Intergovernmental Science and Public Technology—integration of science and technology as an essential resource into the policy and program planning and execution activities of State and local governments, and test and evaluation of selected incentives that the Federal Government may properly and effectively use to increase R&D investment in the private sector where new technology is needed in the national interest.

During fiscal year 1976, the further phase-down of energy research in RANN continued as the Energy Research and Development Administration enlarged its energy R&D efforts. This phase-down included a transfer of technical oversight responsibility for 125 projects being supported at a level of over $21,000,000 in fossil energy, energy conservation, solar energy, and geothermal energy.

Table 9
Research Applied to National Needs
Fiscal Years 1974, 1975, 1976
and Transition Quarter (July 1-Sept. 30, 1976)

(Dollars in Millions)

	Fiscal Year 1974		Fiscal Year 1975		Fiscal Year 1976		Transition Quarter	
	Number	Amount	Number	Amount	Number	Amount	Number	Amount
Resources	228	$29.72	298	$38.84	159	$15.20	38	$ 3.26
Environment	169	25.85	170	23.76	196	26.98	58	6.38
Productivity	135	15.71	164	16.94	196	24.11	50	6.36
Intergovernmental Science and R&D Incentives	26*	0.96*	51	2.84	67	4.34	18	1.01
Exploratory Research and Technology Assessment	57	3.80	17	1.21	19	1.40	2	0.41
Total	**615**	**$76.04**	**700**	**$83.59**	**637**	**$72.03**	**166**	**$17.42**

* The R&D Incentives Program was not included in RANN in Fiscal Year 1974.

RANN looks to small business, with its history of innovation and new technology development, as an important participant in its research programs. This involvement with small business was increased in 1976 through a 2-day RANN National Small Business Conference held in Washington and through increased awards made to small business. The National Small Business Conference provided to some 400 small business representatives information on RANN as well as access to NSF program managers and to representatives of 14 Federal agencies with the largest research and development budgets. During fiscal year 1976, some 56 awards, totaling $5.2 million, were made to small business. This represented 8.5 percent of RANN's funding and exceeded the 7.5 percent minimum level required by the Congress.

Resources

The problems the United States contends with in developing and managing the natural resources it needs are complicated today by increased worldwide demand and competition for resources, and by inadequate incentives for continued technological progress in the production of many resources. The resources program supports research to identify emerging problems and to develop alternate policies and technical solutions.

Resource Systems

The resource systems program, through its focus on system definition, analysis, and evaluation in nonenergy areas, seeks better ways to deal with resource problems. It also provides a way to integrate the results of exploratory research on renewable and nonrenewable resources into this assessment process.

Research on food resource systems has focused on major commodities, such as beef, in order to identify and assess alternative ways to provide nutritious products, meet food quality and safety requirements, and minimize the use of fossil energy and other competitive resource inputs. Researchers at Colorado State University have completed a data inventory of energy and protein and an initial model showing the resources needed for six alternative beef production systems in Colorado. Work at the University of Kentucky has provided preliminary estimates of the potential for producing red meat in areas where forage can be used as the principal feed. And work at Washington University, St. Louis, indicates that organic cropping methods may offer an economically acceptable alternative to the energy-intensive and resource-consumptive conventional feedlot operations, which require grain produced from irrigated land.

Research in other food commodity areas, such as the application of enzyme technology to the processing and storage of dairy products and the identification and evaluation of management alternatives for fisheries in the extended jurisdiction, is expected to yield a better understanding of the consequences of the introduction of new techniques.

Research on energy systems has continued to develop and evaluate improved analytical methods and modeling techniques, expand the needed data base, and create new ways to help design, plan, evaluate, and implement alternate solutions. In a number of areas the program has supported evaluations of the impacts of various technical and policy options on energy supply and consumption. Modeling efforts have created a long-range energy supply model, a simulation model of the world oil market, an alternative leasing strategy evaluation model, and models for better estimation of the energy resource base. Portions of these models have been used by several Federal agencies.

Continuing effort is improving models to include the impacts of potential environmental and economic policy decisions on energy supply, and expanding modeling activities to include nonenergy resources and their relation to the energy supply system. Studies of techniques to improve the efficient use of energy have also been completed, including the effect of alternative electrical rate structures, retrofit strategies for buildings, the use of underground structures, policies to reduce automobile gasoline consumption, and end use energy efficiency. In addition, the program has evaluated the effectiveness of existing legislative measures and developed new strategies for a wide range of energy conservation problems.

Renewable Resources

The three high priority areas for research in the renewable resources program—biomass utilization, innovative biosynthetic techniques, and nonconventional foods—gained their impetus from results of studies such as *The Federal Role in Increasing Productivity of the U.S. Food System,* and *Protein Resources and Technology.*

Research on biomass utilization has focused on innovative technologies to convert wood and wood waste to industrial chemicals. Projects started in fiscal year 1976 have emphasized biological processes for the degradation of cellulose and lignin to sugars and aromatic compounds, which can

be converted to food and other useful materials.

A major area of research on innovative biosynthetic techniques is biological nitrogen fixation. The synthesis of ammonia from molecular nitrogen in the air by various natural biological systems represents the single predominant contributor of "fixed" nitrogen on this planet. However, few people realize how extensive this process really is. Every year throughout the world, approximately 175 million tons of natural nitrogen fertilizer, including 90 million tons on agricultural soil, are fixed by microorganisms, that is, bacteria and blue-green algae. This compares with 40 million tons produced chemically on a worldwide basis, including 9 million tons in the United States. The manufacture of this chemically produced nitrogen fertilizer requires fossil fuels, a nonrenewable resource of decreasing abundance and increasing cost. Obviously, it is important to investigate means to enhance the natural ability of nitrogen-fixing microbes in nature as a way to reduce our dependence on commercial fertilizers.

Nitrogen-fixing microbes contain a delicate feedback mechanism which immediately shuts off further nitrogen fixation as soon as sufficient ammonia has been synthesized to meet the growth and metabolic requirements of the organism. Two projects were initiated in fiscal year 1976 to construct mutants of such organisms in which the feedback mechanism is no longer functional. Results from both projects have been highly encouraging.

The project at the University of Wisconsin, Madison, has produced mutants of the nitrogen-fixing soil organism *Azotobacter Vinelandii* that continue to synthesize ammonia and excrete it into the surrounding medium.

Similarly, the project at the University of California, Davis, has constructed mutants of *Klebsiella*

Nitrogen fixer. Nitrogenase enzyme (crystals of which are shown here in a microphotograph) occurring naturally in some microbes performs the important job of catalyzing the transformation of molecular nitrogen to ammonia needed for plant growth. Research projects are under way to find ways to take advantage of the properties of these microbes to reduce man's need for manufactured nitrogen fertilizers. (Photo by Winston Brill/University of Wisconsin.)

Pneumoniae and a blue-green algae which also excrete ammonia. A mutant of K. *Pneumoniae* provided a 400 to 500 percent increase in ammonia production over the parent strain. Blue-green algae are particularly important since they have the ability to use sunlight as a source of energy and water as the source of hydrogen to reduce molecular nitrogen to ammonia.

In another biosynthetic area, it has been found at the University of Miami that many marine algae occurring in the tropical or subtropical regions are able to use the energy of sunlight to split water and release molecular hydrogen—a potential energy source. During fiscal year 1976, a very active and highly stable blue-green algae was isolated which is five to eight times more active than the best previously known hydrogen-producing microbe.

Nonconventional food research has involved projects in leaf protein, oilseed protein, and methods to overcome barriers that inhibit the use of new protein resources. A project initiated at the University of Wisconsin has produced significant progress in developing a system to harvest and process forage. The system will minimize field losses, maximize nutrient use, and allow farmers to harvest their crops when they are at the height of nutritional quality, without interruption by poor weather. The traditional means to harvest alfalfa requires drying the crop in the field until it reaches a low enough level of moisture for it to be stored in the silo. This is usually accompanied by huge losses, up to 25 percent of dry matter and feed nutrient. In areas where there is frequent rainfall in the early summer, the entire first cutting is often lost. A conservative estimate indicates that losses incurred throughout the Nation during the harvesting of just one crop, alfalfa, exceed $400 million annually. If successful, this research could easily reduce the loss by at least 50 percent.

The lack of an accepted rapid method to assess the protein quality of foods is a major problem facing the food industry, regulatory agencies, and researchers in food technology, nutrition, and plant breeding. It is also a major obstacle to the use of novel sources of protein in food products. The problem has become acute in recent years because of the demands for nutritional labeling on processed foods and growing consumer interests in the quality of all foods. At present, the only method acceptable to the regulatory agencies for determining protein quality is the protein efficiency ratio (PER) test. It is an expensive ($225 to $300 per sample) and time-consuming (minimum of 28 days) procedure using rats as the assay organism, and there is no substitute as yet for it in the quality control of processed food products.

However, the University of Nebraska is attempting to develop a method to predict the nutritional quality of combinations of proteins used in food fortification. They have found that an *in vitro* enzymatic digestion procedure shows promise as a means to predict the protein efficiency ratio of a given source of protein. It is hoped that with additional refinements, such as measurements on the rate of liberation of essential amino acids (e.g. lysine and methionine) and on the response of the digest in supporting the growth of a single cell protozoan, a rapid and inexpensive methodology can be developed.

Nonrenewable Resources

To provide timely technical and economic options to strengthen the Nation's long-term mineral resource posture while achieving its social, environmental, economic, and conservation goals, this program supports research in mineral market behavior and shortages, resource conservation, and advanced processing technologies.

The mineral market behavior program focuses on investment behavior in a number of mineral industries, evaluation of alternative measures of resource scarcity, and international aspects of mineral trade and worldwide mineral demand. Studies on investment behavior were recently completed for the zinc and nickel industries. In the zinc industry, the combined impact of the U.S. zinc stockpile, tariff, and quota policies were shown to adversely affect investment in the domestic industry.

In the area of resource scarcity, it was concluded that the most commonly cited measure of resource scarcity, unit cost, is such an ambiguous indicator of scarcity that it should not be used. Among its deficiencies are the fact that the index is a lagging, not a leading, indicator, that it reveals nothing about future costs of extraction, and that it does not warn of impending physical exhaustion.

In the field of advanced processing technologies, Milton Wadsworth, University of Utah, combined forces with the Martin Marietta Laboratories in Baltimore, Md., to search for alternative methods to process relatively small deposits of low grade copper ores. Such deposits are not currently being used for a number of environmental and economic reasons associated with scale of operations. After examining a number of alternatives, they have narrowed their research to an acid ferric sulfate leach process. A chalcopyrite (copper ore) concentrate is ground to less than 1-micron size in an "attritor" prior to multistage leaching. A key feature resulting from grinding in the attritor is that for a given energy input, up to twice as much copper can be leached as is realized by conventional ball milling. Gold, silver, and sulfur may be recovered as byproducts of the process, and the sulfur produced is

the equivalent in purity to distilled sulfur. Preliminary economic estimates by Martin Marietta Laboratories show an investment of $620 per ton of copper for a 45,000-ton-per-year plant. This compares with $1,500 per ton for a conventional 130,000-ton-per-year plant.

Environment

RANN environmental programs are directed toward the improvement of scientific bases for the mitigation of major environmental hazards and the rational management of environmental resources. Ultimately, the results of this research can save lives, reduce injury and property damage, and relieve ecological, social, and economic disruption. By encompassing both manmade and natural hazards, these programs provide systematic analyses of major environmental hazards. This, in turn, permits a unified approach to the formulation of policies.

In 1976, research in RANN's environment program was supported in seven separate areas: (1) regional environmental management, (2) environmental aspects of trace contaminants, (3) environmental effects of energy, (4) weather modification, (5) earthquake engineering, (6) fire research, and (7) societal response to natural hazards and disasters. In fiscal year 1976 the fire research program was transferred, along with personnel, to the Department of Commerce. Similarly, research under the environmental effects of energy program was phased out and the new Energy Research and Development Administration assumed responsibility for it.

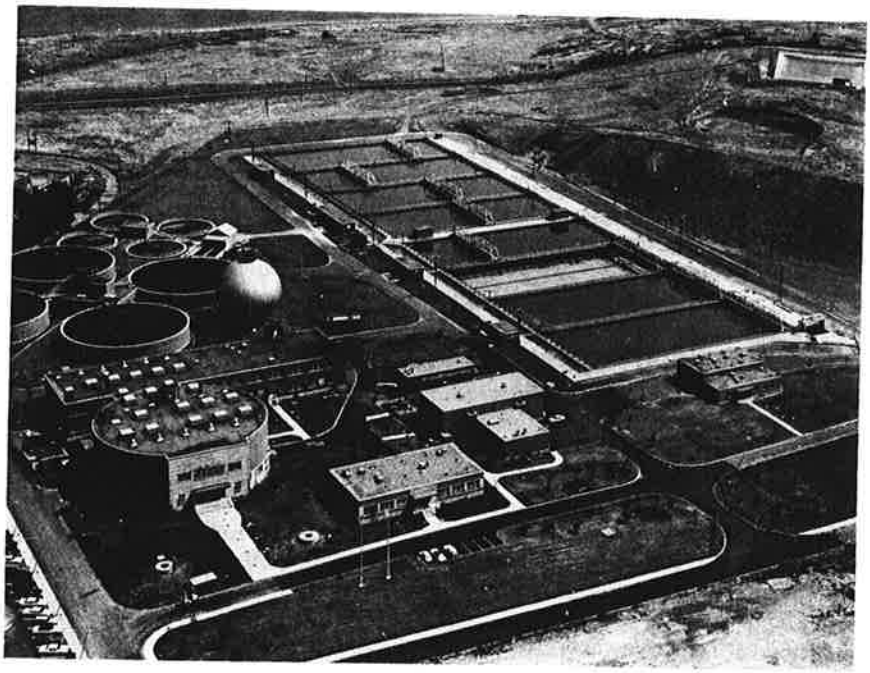
Regional Environmental Management

Research supported by this program synthesizes and evaluates procedures to manage factors that significantly affect the health and well-being of humans and the regional ecosystems upon which they depend. Solutions to problems of regional ecosystem quality require consideration at a scale sufficiently large to provide measureable relationships between population changes, land use, material, energy, and economic factors.

During 1976, specific program areas were: (1) improved economic and ecological bases for environmental decisionmaking, (2) methods for predicting land use and other secondary consequences of environmental control, (3) management of residuals from municipal and industrial sources, and (4) synthesis and testing of regional environmental management strategies.

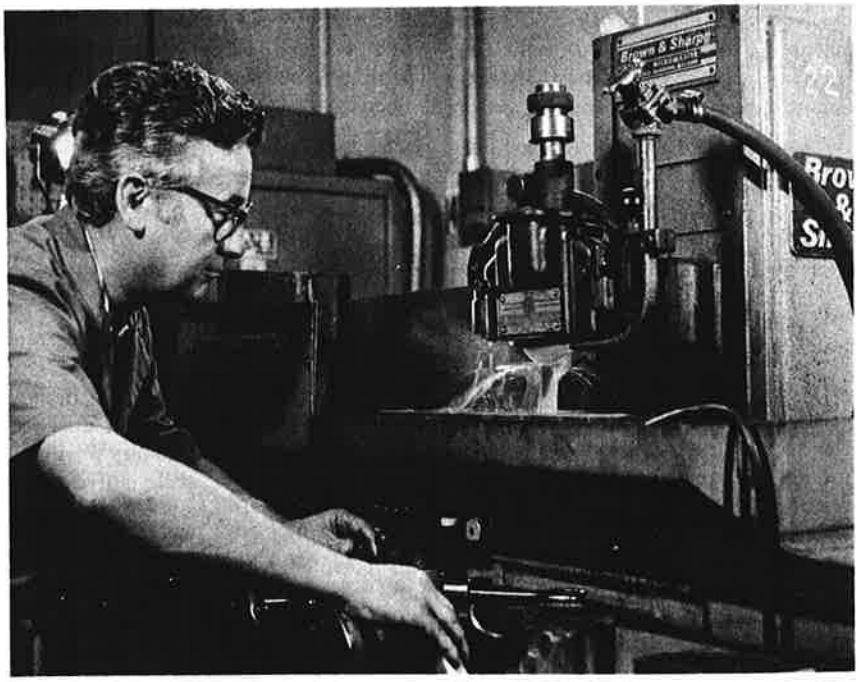
Scientists at the University of California, Davis, are continuing their work with the California Tahoe Regional Planning Agency in the preparation of a general plan for the development of the Lake Tahoe basin. The regional plan will correlate land use (including water and air resources), transportation, conservation, recreation, and public services and facilities.

Research under the direction of John G. Trump at the Massachusetts Institute of Technology has led to the design and construction of a facility for determining the feasibility of



Municipal sludge. Management of sludges produced by the Nation's increasing number of municipal wastewater treatment plants is an already large and growing problem. The Deer Island Metropolitan District Commission's (Boston) Wastewater Treatment Plant is cooperating with the Massachusetts Institute of Technology in conducting an experiment to determine the feasibility of using high-energy electrons as an economical way to disinfect sludges for safe handling.

using high energy electrons to disinfect municipal wastewater sludge and treated effluents. Disinfection of sludges may be necessary to reduce risk of infection that may be associated with placement of sludges on agricultural soil. An in-line unit, located at the Deer Island Wastewater Treatment Plant of the Boston Metropolitan District Commission, began operating in May 1976. The standard, high energy electron source installed there will deliver a dose of 400,000 rads, which is anticipated to be adequate for disinfection of up to 100,000 gallons of sludge per day. The cost of electron treatment for disinfection is estimated to be in the range of $10 per dry ton of sludge. When combined with subsequent direct injection of sludges into soil at an additional cost of $15 per ton, the total represents a substantial savings from the current costs of managing sludge, which range up to $100 per dry ton. Electron-radiation treatment of sludges to achieve disinfection is expected to be much less costly than use of radioactive isotopes such as Cobalt 60 and Cesium 137 or the use of heat. Indications are that electron-treatment of the sludges will improve their capability for being dewatered, thereby reducing the cost of transportation to disposal sites.



Environmental warning. NSF-supported scientists, using a new method of chemical analysis, found that some formulations of cutting fluids, used in metalworking tools like this one, contained possibly hazardous amounts of nitrosamines, a family of compounds that are suspected human carcinogens.

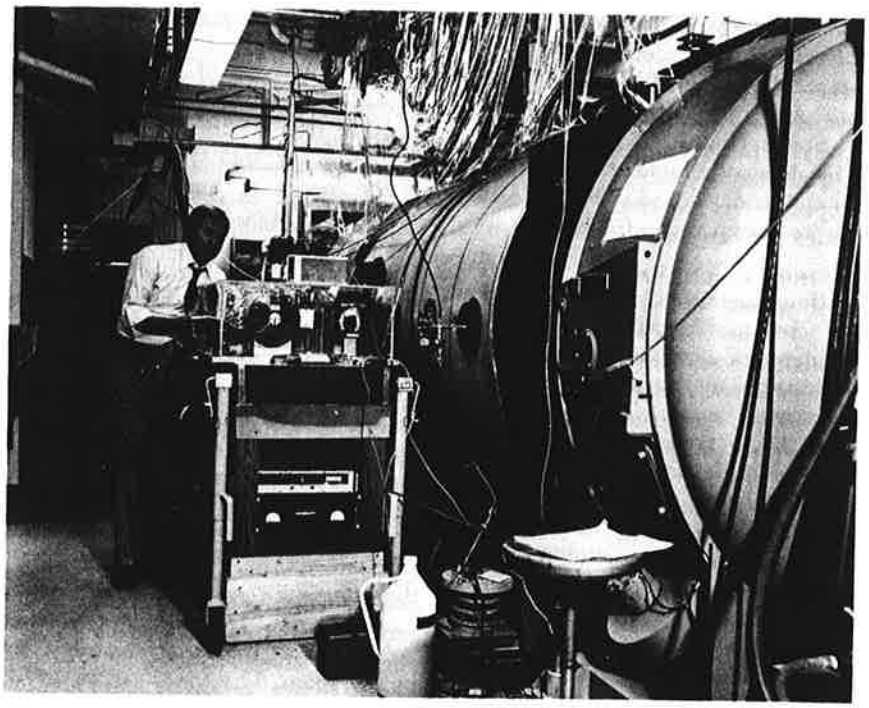
Environmental Aspects of Trace Contaminants

The environmental aspects of trace contaminants program is concerned with the identification, quantification, and assessment of the impact of the spread in the environment of hazardous chemical materials, both man-made and naturally occurring.

Using a sensitive new detection method called thermal energy analysis, NSF-supported scientists at Thermo Electron Corporation in Waltham, Mass., have found large amounts of nitrosamines in eight brands of cutting oils that are widely used in industry to reduce friction and heat in cutting metals. Nitrosamines, formed from the combination of nitrites and amines, both of which are common in our environment, are known to cause cancer in animals and are suspected of causing it in humans. David Fine of Thermo Electron had previously reported to the American Chemical Society that nitrosamines routinely contaminate several herbicides, including one used on tomato and other food crops.

In collaboration with the Harris County, Tex., Pollution Control Department, researchers at Washington University have collected effluent water from several plants discharging into the Houston Ship Channel and subjected it to the "Ames test," a bacterial test for the presence of mutagenic (and probably carcinogenic) chemicals. Effluents from a pulp plant, an oil refinery, a steel mill, and two industrial waste treatment plants were studied. Of the five sources tested, the black liquor from the pulp plant was clearly negative; effluents from the refinery and one industrial waste treatment plant were clearly positive and must be regarded as delivering "presumptive" carcinogens into receiving waters. Results from the second waste treatment plant were borderline. Results from the steel mill effluent were ambiguous, but when separated into five components by thin-layer chromatography, two of the five were mutagenic and one was toxic to the bacteria. Extracts of particulate matter from St. Louis and Chicago air have also been subjected to the Ames test. Mutagenic materials were definitely present in both and more concentrated in material from the central cities than in that from outlying areas.

At the University of California, Davis, an NSF-supported research



Smog chemistry. As a way to learn more about the sequences of chemical reactions that occur in polluted air, James N. Pitts, Jr., at the University of California, Riverside, uses a 200-cubic-foot reaction chamber for simulation experiments.

group has developed an automated methodology for analyzing aerosol samples; it has since been adopted for routine use by the California Air Resources Board. This method is many times faster and about one-fourth the cost of the chief competing method, and the annual saving in California alone will be about equal the cost of the project. And in southern California, research at the University of California, Riverside, is defining the chemistry of the photochemical smog-forming process. The intent there is to identify the exact roles of the primary pollutants (hydrocarbons, nitrogen oxides, carbon monoxide, sulfur dioxide) that react in the air to form bio-irritants such as ozone. The project has identified several exotic substances in synthetic smog mixtures that are likely to modify the course of the smog-forming process or to have adverse health effects. It has also resolved a major controversy about oxidant measurements, which will significantly modify the manner in which local authorities declare pollution alerts.

Environmental Effects of Energy

The development of major new technologies to extract, store, transport, or convert energy will likely require substantial expenditures of public and private funds as well as several years or decades to develop. During 1976, this program sought to identify the environmental effects of energy development and to design means of minimizing the associated environmental damage.

Research at the University of Southern California on the chemistry, fate, and removal of contaminants from low and medium salinity geothermal wastewaters indicates that most effluents can be used for drinking or agricultural purposes if only one, two, or at most three elements are removed—those being arsenic, boron, and fluorine. Although it has been shown that geothermal waters carry a large number of trace metals, only those three occur in amounts considered harmful to man in many of the low to medium salinity waters.

Research on the feasibility of using large artificial islands as locations for multiplant industrial complexes was carried out by the College of Marine Studies at the University of Delaware with assistance from Texas A&M University, Frederick R. Harris Inc., and Gilbert Associates, Inc. The project evaluated the economic, engineering, legal, and environmental possibilities of large artificial industrial port islands located off the U.S. Atlantic and Gulf Coasts. The initial studies show that, with known technology, artificial islands in the range of 5,000 to 10,000 acres can be built at a present cost of between $1 and $2 billion per island. Because of the scarcity of land available for industrial siting and because of the proximity of markets, such islands—in spite of their cost—appear to be economically feasible off the northeastern coast of the United States.

Weather Modification

The weather modification program continues to support the development of improved techniques and capabilities and to explore the impact of weather modification on society. Hail suppression, precipitation augmentation, improved weather for agriculture, and inadvertent weather modification are some of the areas being investigated.

Climate and Food, a recently completed study by the National Academy of Sciences/National Research Council on the effects of weather and climate on agricultural

production, looked at climatic fluctuations, water and land resources, plant breeding, crop and livestock management, pest management, weather modification, and strategies for developing countries. It found that weather is a primary determinant of agriculture and that weather modification offers major economic and production benefits.

Project METROMEX results indicate that the St. Louis urban-industrial area is an important source of cloud condensation nuclei, which form by the gas-to-particle conversion of SO_2 and subsequent particle growth processes. These aerosols are a major contributor to the formation of stable haze commonly observed during air pollution episodes. The two- to threefold increase in frequency of precipitation initiation events in urban-influenced air is attributed to the effect of the increased number of large condensation nuclei on the coalescence (warm rain) process.

Earthquake Engineering

This program, supporting research to improve our understanding of the physical and societal effects of earthquakes, concentrates on: (1) developing civil works design procedures incorporating disaster-resistant provisions, (2) investigating the social and economic effects of earthquakes, and (3) transferring the knowledge and procedures to designers, decision-makers, public officials, and the general public.

A group at the University of California, Berkeley, doing research on soil responses to earthquakes, has developed computer programs widely useful in the design of earthquake-resistant structures. The programs are now used by virtually all engineering consulting firms engaged in earthquake analysis related to construction. One of the programs has been adopted by the Structural Engineers Association of California and is being incorporated in the Uniform Building Code of the International Conference of Building Officials. And the American Association of State Highway Transportation Officials incorporated standard tables and curves developed in this research into its design codes for bridges.

Results of NSF studies on tsunami (earthquake-caused waves) behavior will be used by the Nuclear Regulatory Commission in evaluating applications for nuclear powerplants in coastal areas. The President's Council on Environmental Quality has also made use of the results of these tsunami studies to estimate potential oil spillage due to earthquake effects on structures in the Gulf of Alaska and to estimate the relative frequency of tsunamis on various development plans. Other organizations currently using these results include the U.S. Army Corps of Engineers, Pacific Gas and Electric Company, and Puget Sound Power and Light Company.

Two cooperative agreements in earthquake engineering with the Soviet Union are now in operation. The first, on environmental protection, provides for joint research programs in engineering seismology. Projects are currently under way in the areas of strong ground motion and induced seismicity from reservoir impoundment. The second agreement, on housing and other construction, provides for joint research in the seismic design and analysis of structures. A benefit already received from this program is a sophisticated and novel approach developed by the Soviet Academy of Sciences to estimate building site seismicity due to point, line, and distributed seismic sources. Their computer programs have been implemented at the Massachusetts Institute of Technology as part of a comprehensive seismic risk project at the savings of several man-years of research and computer program development.

Fire Research

The objectives of this program, transferred in 1976 to the Department of Commerce, were to reduce fire losses through the improvement of the design of buildings to resist and contain fires, the improvement of flammability testing procedures, and the determination of the factors leading to more effective fire detection and control systems.

A third in a series of bedroom fire tests was conducted jointly by Harvard University and Factory Mutual Research Corporation with the cooperation of the Norwood, Mass., Fire Department. The purpose of these tests is to understand the phenomenon of "room involvement," the sudden change from a small, localized fire to the simultaneous ignition of all the other combustibles in the room. The first test, in 1973, experienced rapid fire growth, or "room involvement," 17 minutes after ignition; the second test, in 1974, using an identical room layout but slightly different materials, experienced rapid fire growth in only 7 minutes after ignition. The third test, identical in both layout and materials to the second to determine the reproducibility of such a realistic full-scale test, was the most extensively instrumented room fire test ever run. "Room involvement" occurred just 20 seconds sooner than in the second test, with only minor differences in the preceding flame spread. It is expected that these tests will lead to a new approach to fire safety standards and regulations based on realistic fire tests. Small-scale flammability tests currently available, unfortunately, can lead to unwarranted conclusions and the marketing of hazardous materials, albeit unintentionally.

An elevator simulation investigation has shown that elevators, properly equipped, can be used efficiently in the redistribution of people within a tall building and for the movement of people away from

fire danger zones through improvements in elevator dispatcher logic design. Simultaneous elevator cab assignments to the same floor, zones with overlapping floors, floating cabs, or cabs parked evenly throughout the zone may give superior means to handle emergencies than the common practice of taking all elevators to the lobby to provide for fire fighter transport.

Societal Response to Natural Hazards

This program seeks to accumulate, analyze, and test knowledge about individual, organizational, and institutional behavior associated with major natural disasters for all relevant time periods: preimpact, impact, rescue, relief, restoration, rehabilitation. This body of information will permit development and testing of procedures, techniques, customs, structures, and policies for individual and community preparation for response to and recovery from natural disasters.

The Institute of Behavioral Sciences of the University of Colorado has completed a comprehensive "Assessment of Research on Natural Hazards." This study will strongly influence future research both at NSF and in other Federal agencies. For example, a recently established Community Preparedness Program in the National Oceanic and Atmospheric Administration was in part a response to that agency's participation in the University of Colorado project. Also, through study of flood losses, this project developed a simulation model that has been adopted by the Corps of Engineers.

Advanced Productivity Research and Technology

One of the Nation's most important economic problems over the past decade has been the declining rate of productivity increase. The advanced productivity research and technology program provides a scientific and technical basis to increase productivity through research on the effects of public policies on productivity and on the better use of human resources, technology, and capital.

In fiscal year 1976 this program emphasized studies to improve productivity in the delivery of public services, to assess the benefits and costs of Federal assistance programs to State and local governments, to analyze the net effects of Federal and State regulation on industry and the public, and to facilitate the adoption of technology to improve private sector industrial productivity, with particular attention to the joint contribution of industry and universities.

Public Sector Productivity

This program supports research to analyze and measure the effectiveness, efficiency, and equity of public service delivery systems. Major projects are in the areas of the social and economic effects of telecommunications innovations in providing services, the potential of technology for improving local government operations, and the productivity of health delivery systems through improved medical instrumentation technologies.

In 1976, the Cable Television Information Center of the Urban Institute conducted a national survey of social service applications of cable TV. The study demonstrated that a vast range of applications has been attempted over the past 10 years, but that purely local initiatives have proven very difficult to maintain. A computer simulation, which models the costs of development and demand for urban cable TV (CATV) services and estimates the economic consequences of alternative regulatory CATV policies, has been used by the cities of Cleveland and Detroit for planning CATV policies. Research on the model, at Johns Hopkins University, was supported by the Foundation and the Federal Communications Commission.

Following a major conference on children and television, supported by the NSF, the Ford Foundation, and the Markle Foundation, NSF initiated support of eight research projects on the social impacts of broadcast television in areas including advertising, role-learning, violence, and cultural change.

During fiscal year 1976, the Foundation supported research on alternative organizational arrangements by local government for the delivery of four urban services—police, fire, public health, and solid waste management. Extensive data have been collected on the organizational and legal arrangements involved in the delivery of these services in Standard Metropolitan Statistical Areas of less than 1.5 million population; by fiscal year 1978 case studies of the performance of these organizational arrangements will be completed.

The first phase of a project on development of a productivity measurement system for State government has been completed. It includes systems to assess the efficiency and effectiveness of foster care and nursing home services within the State of Washington. A subsequent phase will involve evaluating service delivery and establishing the transferability of the measurement system to other services within the State.

Research on the delivery of civil law services includes studies of how courts can be organized more efficiently, how technologies such as videotape and computers can enhance

court productivity without diminishing the quality of justice delivered, and how clients can organize more effectively to acquire legal services. In the latter area, the Futures Group of Glastonbury, Conn., produced a handbook entitled "Prepaid Legal Services: How to Start a Plan" and a policy-oriented reference book entitled "Prepaid Legal Services: Socioeconomic Impacts." The American Bar Foundation of Chicago, Ill., produced a series of articles and monographs dealing with types of legal service plans, their organization, purpose, and regulation.

In instrumentation technology, University of California, San Francisco, researchers constructed a gas-filled, proportional chamber camera to show the spatial distribution of radiopharmaceuticals labeled with positron-emitting radionuclides. The scientific announcement of this device was listed as one of the "Highlights of 1975" by the Society of Nuclear Medicine. The camera is being used in tests supported by the National Cancer Institute to investigate its potential for improving the monitoring of patient recovery using minimum radiation exposure.

Public Policy

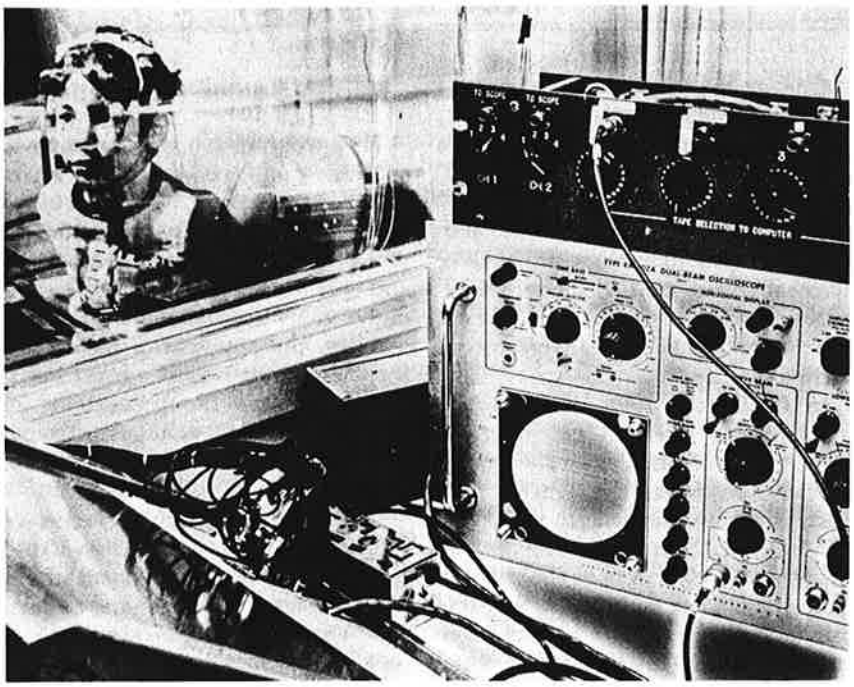
Public policy research aims to develop systematic assessments of the effects of public policies on national productivity in both the public and private sectors. Projects are intended to provide timely, relevant information to assist policymakers in their deliberations on specific issues. Research support emphasizes productivity measurement, regulation, distribution and equity, and private-public sector relationships.

Virtually all industries are subject to broad regulatory statutes, such as antitrust laws and the Consumer Product Safety Act, and can be subject to specific regulations that may have significant effects on their structure, behavior, and performance. In fiscal year 1976, the Foundation initiated research on the impact of regulation in consumer financial services, in ground beef production, and in copper wire processing. These awards were made to provide better understanding of the cumulative impact of regulation at the Federal, State, and local levels on the price, supply, and quality of the goods and services produced in these sectors. Such information will be useful to regulators, labor, business, and public interest groups in making the regulatory process more efficient and equitable.

The economic consequences of current ratemaking procedures used by public utilities are being studied and compared with alternative procedures which might reflect prices under competition. An NSF-funded effort at the Rand Corporation provided the Los Angeles Department of Water and Power with an analytical basis for the establishment of new residential electricity rate structures.

A two-volume *Policy Analysis Source Book*, prepared by the National Planning Association, was published in March 1976 by the U.S. Government Printing Office and is currently available there. The *Source Book* contains about 3,750 abstracts of significant books, articles, and reports concerned with policy issues and the analysis of social programs, and a list of about 775 titles recommended by experts as additional sources for valuable policy information. The *Source Book* is a comprehensive reference work that can be available at deskside to provide easy access to the contents of many of the most useful studies that assess means of meeting the Nation's social goals and weigh social policy alternatives.

As part of a nationwide study of



Brain waves. At New York Medical College, an 8-year-old boy is tested by a computerized "neurometric" series to help diagnose whether he has a specific learning disability. The technique may prove feasible for early identification of such disabilities and also for diagnosing stroke and senile dementia.

information systems and their impacts on cities and counties, the Public Policy Research Organization, University of California, Irvine, has produced two directories, the *County Information Systems Directory* and the *Municipal Information Systems Directory*. The guide to municipal computerized information systems throughout the United States includes 403 cities with populations of 50,000 or more, and the guide to county computerized information systems includes 310 counties with populations of 100,000 or more.

A project at Duke University has examined some of the issues raised by demographic changes, such as the decreased rate of population growth and concomitant changes in age distribution. A central question is the relationship between age structure and the economic security of the elderly.

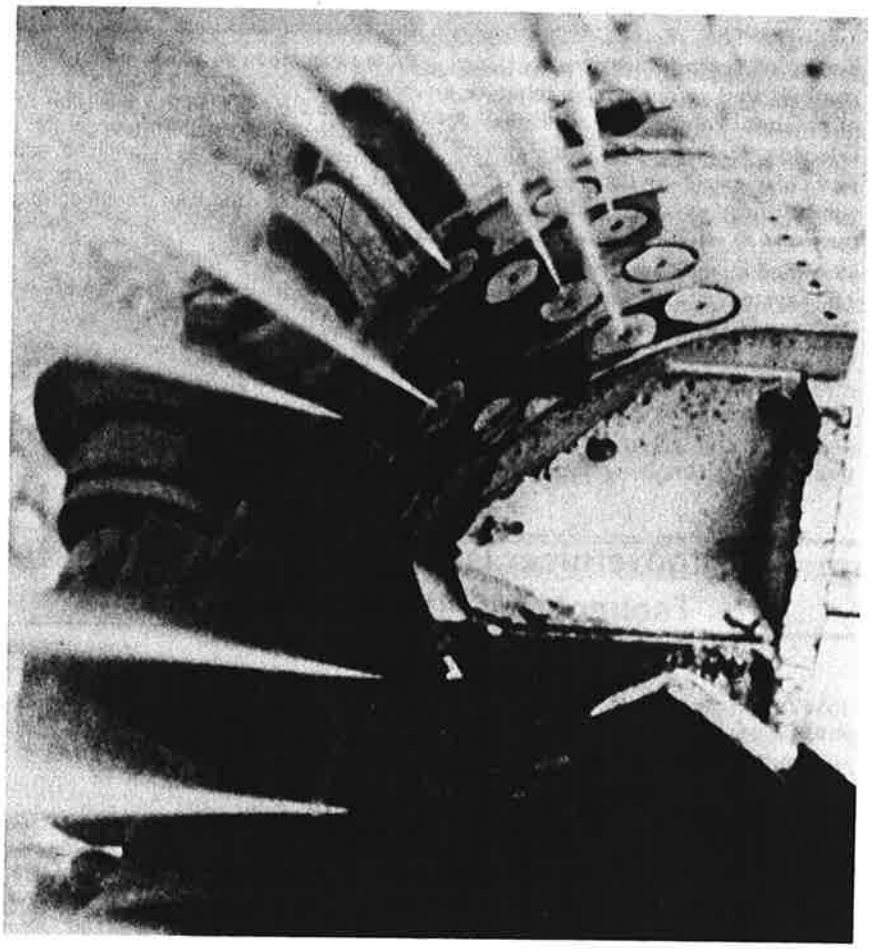
A policy report issued by a research team at the University of Southern California working on the "Cultural Context of Aging" is concerned with the transportation needs of the elderly. The report concludes that the elderly have substantial current transportation needs and that a demand-response system is probably necessary if significant improvement in transportation service to the elderly is to be provided.

A project at the University of Maryland has been investigating better ways to determine cost-benefit ratios for product safety standards. The study concluded that the size range 0-6X sleepwear flammability standard, used as the exemplar case, was a cost-effective means of providing protection to the consumer.

Research at the Brain Research Laboratory, New York Medical College, has resulted in the development of a new tool to diagnose dysfunction of the brain. The method uses computer averaging and analysis of the brain waves produced as a result of providing stimuli such as clicks and light flashes. The research has focused on the diagnosis of learning disabilities but shows promise for the diagnosis of stroke and senile dementia as well. The technique shows promise for consideration in mass screening and early identification of children who will develop learning problems, permitting remediation before the problem causes lasting harm to the child.

Private Sector Productivity

The private sector productivity program emphasizes studies to identify and test technologies well suited for productivity improvement in areas where the private sector has little incentive to invest in research. During fiscal year 1976 progress continued in increasing excavation rates and reducing costs of subsurface construction. Field testing of a water-jet-assisted tunnel boring machine has been completed by the Colorado School of Mines, and designs for incorporation into commercial units are now being considered by industry. Ground-probing radar was used successfully by ENSCO, Incorporated, Springfield, Va., in a pilot tunnel of the Washington, D.C., Metro to delineate and locate geological and

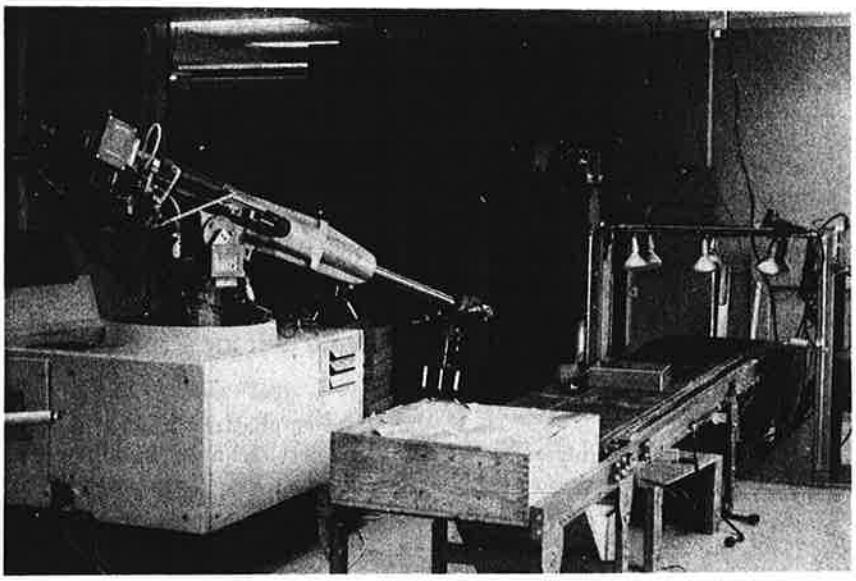


Rock cutter. Research on high-pressure water jets mounted on a tunnel-boring machine has shown them to significantly improve its performance. Commercial users are assessing the jets for adoption on their boring machines.

hydrologic features of a metamorphic rock mass at ranges of up to 50 feet. The Massachusetts Institute of Technology's hard rock tunnel-cost model is now being used in conjunction with the construction of tunnels in New Hampshire and Colorado. A study was completed by the National Academy of Engineering identifying the Nation's drilling R&D needs to develop U.S. energy resources.

In production research and technology, a computerized automatic part recognition system has been developed at the Stanford Research Institute for automatically identifying and determining the position and orientation of each part in a set of diverse parts, such as foundry castings. The method relies on a library of feature-measurement subroutines that compute characteristics of potential value for identification. A selection strategy uses examples of particular parts to determine which subroutines to call, and their sequence, so that each part can be identified in less than one-half second. This system also permits processing images of objects on a moving conveyor.

Basic work on parts description at the University of Rochester has progressed far enough to permit the design and implementation of a system that may offer a breakthrough in drafting as well as application to automatic process planning operations. Dimensioned drawings are automatically produced by providing the system with part definition information.



Parts recognition and handling. In a Stanford Research Institute experiment, a robot arm moves to pick a part out of a box. Lights at the end of the moving conveyor illuminate the objects for a television camera. The resulting image is processed by a computer utilizing pattern recognition and decisionmaking algorithms. The part is identified, its position is determined, and the arm is told how to orient the part for the next assembly step. This is one of several projects aimed at improving the productivity of American manufacturing processes.

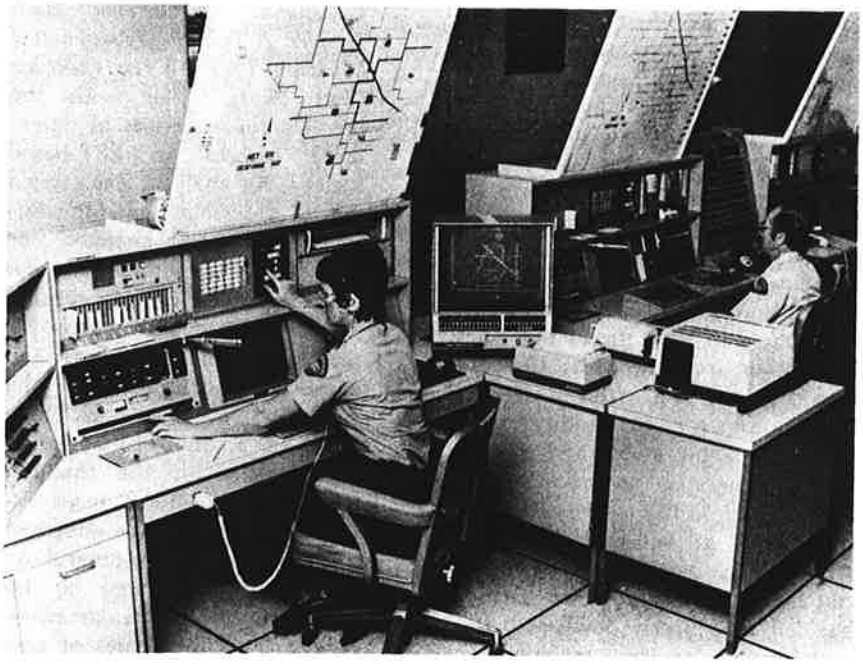
Intergovernmental Science and Public Technology

Activities in this area focus on the public sector (State and local governments) through the intergovernmental program and on the private sector (primarily small business) through the industrial program. Elements of the continuing experimental R&D incentives program, which includes projects in both the public and private sector, are now integrated into either the intergovernmental or industrial program.

Intergovernmental Program

The intergovernmental program facilitates the integration of science and technology into the policy formulation, program planning, and program execution activities of State and local governments. During fiscal year 1976, activities in the local government program focused increasingly on State, regional, and national networks to aid the development and interchange of solutions to problems faced by cities, counties, and other local governments. In addition to the California Innovation Group, the first State-based network, which became a private, nonprofit corporation during the fiscal year, grants were made to plan and initiate additional innovation groups, one in Ohio and another in New England.

The Foundation continued to emphasize activities to help local governments build national networks to develop and share technology. The Urban Consortium for Technology Initiatives (the 27 largest American cities and six urban counties) was strengthened by a grant to the U.S. Conference of Mayors. Federal mission agencies such as the Departments of Housing and Urban Development and Transportation and the Environmental Protection Agency helped to support the functional task force activity of the Consortium. NSF also initiated a special pilot program,



Emergency services. The California Innovation Group, a statewide network to provide science advice to local governments, has performed the requirements analysis and conceptual design for this computer-assisted dispatch system for a local police force.

involving both the Urban Consortium and the Urban Technology System (27 cities in the 50,000 to 500,000 population range), to develop better ways to integrate direct local government inputs into NSF activities to define problems, set priorities, conduct research, and use results.

The State government (executive) program, during fiscal year 1976, focused on various aspects of policy and resources management. In the policy area, growth was selected as the initial area for concentration, and an award was made to the Commonwealth of Massachusetts to help develop a comprehensive approach to growth policy management. At the same time, a grant was made to the Council of State Governments to lay the groundwork for more effective use of science and technology for growth management in other States. In the resources management area, budgeting and financial management activities are the major foci for the program, and NSF supported exploratory and developmental work with the National Association of State Budget Officers.

During 1976, the State government (legislative) program continued to emphasize the development of new approaches to incorporating science and technology into the legislative process. An award was made to the State of Minnesota to establish such capability. The Foundation also strengthened the new emphasis on regionally based, functional activities with grants to the Northeast Energy Project and the Fort Union Coal project, involving North and South Dakota, Wyoming, and Montana. Support was continued in 1976 for the Committee on Science and Technology of the National Conference of State Legislatures. During the year, the State legislatures of the Nation displayed increasing interest in heightened use of science and technology.

The fourth program area, science and technology resources, focuses on the institutional resource bases (such as institutions of higher education, Federal laboratories, private nonprofit organizations, and the private sector) that offer potential for the support of State and local government. Most activity in this area during 1976 involved exploratory work on the issue of academic public service and on the development and strengthening of the Federal Laboratory Consortium, a grouping of more than 60 nondefense and defense laboratories designed to help Federal laboratories as a group contribute to the amelioration of domestic sector problems.

Industrial Program

The industrial program is designed to stimulate increased non-Federal investment in research and development and accelerate the commercial application of research results. To reach these goals NSF supports work to help identify, test, and evaluate the incentives that can be used to encourage R&D investment and the barriers that might impede it.

The premise for the industrial program is that new and improved processes, products, and services are important elements of technological progress through which advances in economic status and standard of living take place. Since innovation and invention are most likely to occur in small (rather than large) firms, the program places an emphasis on small business.

The industrial program has achieved considerable success in the area of entrepreneurial education and the initiation of new business ventures through Innovation Centers at the Massachusetts Institute of Technology, Carnegie-Mellon University, and the University of Oregon. The necessary practical experience is provided by continuing interactions with individual investors and businessmen.

This creative atmosphere has already led to the development of 27 new products, and 24 businesses have been initiated or assisted through Center activities. These include a detector of precious metals being manufactured by Hetra Corporation, a capacitance meter produced by ECD Corporation, and security devices marketed by Compu-Guard, Inc. A total NSF investment in specific projects of $221,750 has already stimulated private sector investment of $791,800 and generated sales in excess of $30 million over 3 years. Over 800 new jobs (including subcontractor suppliers) have been created. This alone is expected to produce annual Federal tax revenues twice the $3,000,000 total NSF expenditure for all Innovation Center efforts for 5 years.

Fragmented industries have been coupled to university and industrial resources through the Cooperative Research Experiment, and the industry-directed research has resulted in new or improved products with immediate user acceptance. An arrangement with North Carolina State University and eight furniture companies has developed a new construction technique—the Clark chairframe—which conserves wood by using small pieces and is 30 to 40 percent lighter in weight than conventional construction. It reduces costs by 20 to 44 percent, and the joint strength has been doubled. Fox Furniture Company in North Carolina and Noritage, Inc., in Wisconsin, have already adopted this technology in their production lines. In another area, the Mitre Corporation is cooperating with the electrical utility industry to modify steam boilers to allow stable and efficient turbine-generator operation in the range of 135 to 185 megawatts rather than only at full-load conditions. Also, MIT's participation with five companies in the polymer industry has led to a newly developed, low-cost injection molding technique for polyurethane for which licensing arrangements are currently being made. Each of these industry-identified projects involves a high degree of cost sharing. Both the number of participating industries and the degree of private cost sharing are increasing for these experiments.

Exploratory Research and Technology Assessment

The exploratory research and technology assessment program supports studies on selected problems that have potential for major national impact. Gaps in the spectrum of existing research relevant to national needs are approached through problem assessment and definition studies, exploratory research projects, and technology assessments.

NSF continued its emphasis in 1976 on studies of the full range of societal effects that may stem from the introduction, extension, or modification of a technology, with the overall objective of developing a better information base for policymaking and decision processes at all levels of society.

Some of the areas reported on in this past year include:

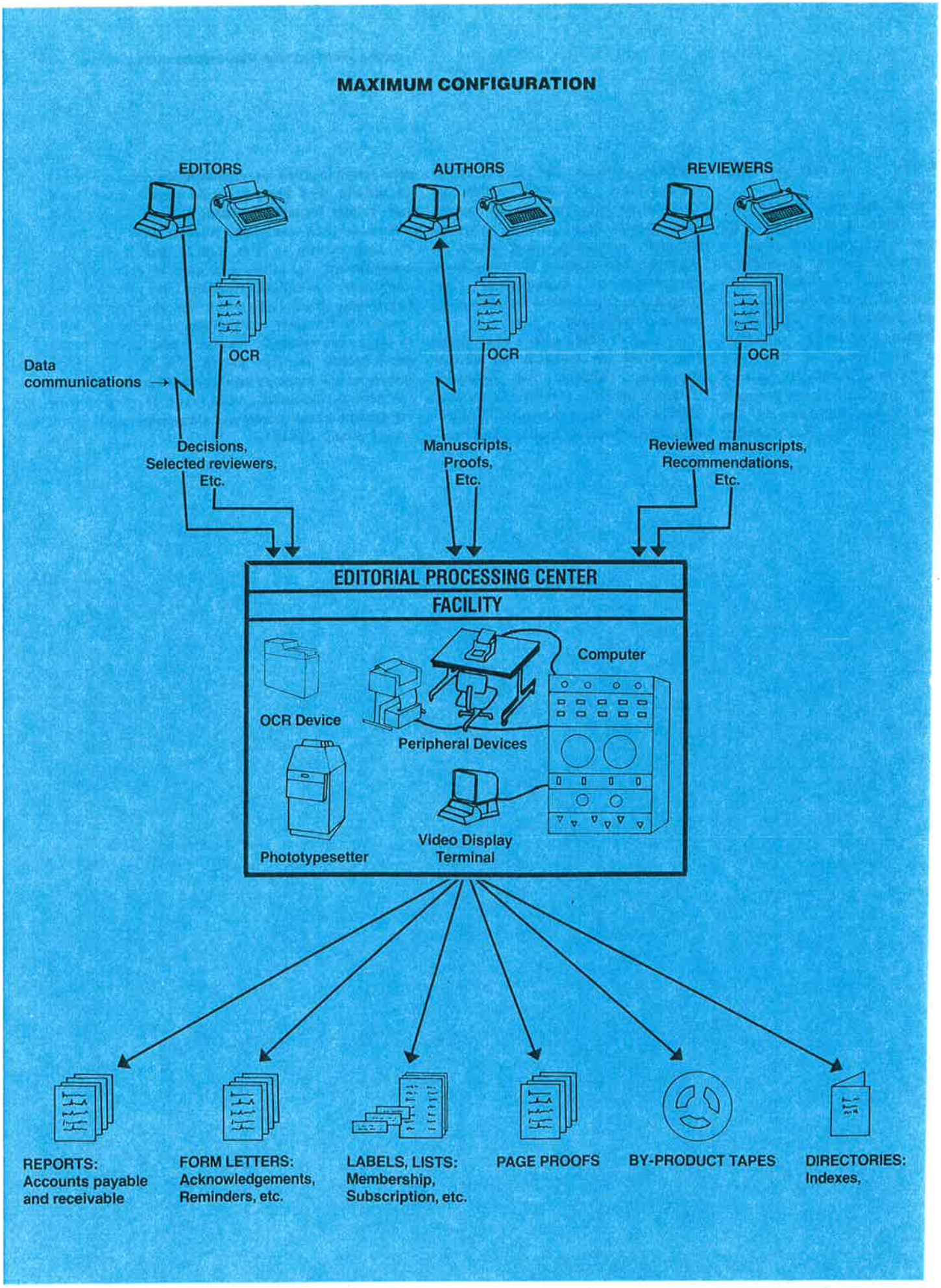
- Electronic funds transfer. Significant changes in the financial industry and the regulatory system under which it operates are probable with the use of electronic funds transfer (EFT) technology, according to a report prepared by Arthur D. Little, Inc. The report, *The Consequences of Electronic Funds Transfer: A Technology Assessment of Movement Toward a Less Cash/Less Check Society*, deals with the possible consequences of movement toward an EFT-based society. An analysis was carried out to determine how the impacts can be changed or mitigated, depending upon which path to EFT is chosen. The study proposes means for monitoring EFT activities and suggests institutions for the resolution of issues as they arise. In addition to assessing the impacts on the financial industry, the study team investigated the possible effects of EFT on business in general, on the government, and on individuals, with particular attention paid to the issues of personal privacy, freedom of choice, crime, consumer behavior, and methods of information handling.
- Geothermal energy resource development. Some potential futures for geothermal energy in the United States were studied and evaluated by a team at the Futures Group, which made recommendations concerning exploration, use of geothermal resources, and research and development that can help policymakers in Congress and in Federal agencies capture the desirable aspects of this energy resource while avoiding its pitfalls. Recommendations include: the use of a single environmental impact statement for large blocks of land; adoption of the lead agency concept to minimize Federal, State, and local government overlap of regulations; the building and operation of demonstration plants; the creation of "resource longevity insurance" to minimize risk of early field depletion, and the

creation of a data exchange center.

Additional results in the exploratory research and technology assessment program included a report, *Toward a National Ocean Policy: 1976 and Beyond,* produced by the Ocean Policy Project of the School of Advanced International Studies at Johns Hopkins University. The report analyzes the results of the 1975 Geneva session of the United Nations Law of the Sea Conference; presents alternative treaty outcomes in the 1976 Law of the Sea Negotiations; outlines options for U.S. ocean policymakers in such fields as national security, commercial navigation, marine environment, fisheries, mineral resources, and scientific research; and stresses the need for a comprehensive management approach to ocean uses, both nationally and internationally.

As part of NSF's effort to improve the use of the research the RANN programs support, the Research Triangle Institute reported on 30 case studies concerning the use of RANN-supported research results. The projects were selected as representative of efforts that have received good use. It was found, for example, that use of research results was influenced by such factors as: the stature and commitment by the principal investigator; adequate funding for utilization; good timing for the interests of the user community; continuing professional liaison; user participation in the project; high quality of the research and convincing research results; and involvement of the project team in communication and use of project results.

MAXIMUM CONFIGURATION



Scientific, Technological and International Affairs

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The Foundation's programs in Scientific, Technological and International Affairs address a broad range of scientific and technological issues of concern to policymakers. Through these programs NSF collects data, supports research, conducts studies, administers international science activities, and undertakes science and technology policy analysis. The purpose of these endeavors is to provide analysis and options or direct assistance to the scientific and technological community in better meeting national and international economic and social objectives. The three main areas of activity are: (1) science and technology policy; (2) scientific and technological data and information; and (3) international scientific and technological activities.

The policy research and analysis program supports policy formulation by analyzing options for enhancing the contribution of science and technology to national issues. For example, during this past year, the staff prepared working papers for the Government Task Force on Inadvertent Modification of the Atmosphere. These are now being used by the Federal Coordinating Council on Science, Engineering, and Technology to develop new Federal R&D programs on the biological and climatic effects of stratospheric ozone. On another important national issue, the Foundation's working group on energy, resources, and environment sponsored a workshop on long-range energy demands. Government, industry, and academic participants addressed such topics as forecasting electricity demand, comparing future energy use in major consuming sectors, and possible directions for national energy conservation policies.

In the science resources studies program, which maintains the national data base for planning and policy formulation in the area of science and technology resources, special emphasis is placed on R&D funding and science manpower. NSF carries out periodic surveys and studies of all elements of the national science and technology enterprise in support of decisions regarding the allocation of national resources. During this past year, the President released the seventh annual report of the National Science Board, *Science Indicators 1974*, a report prepared with the assistance of this program and other NSF staff. This report presents the quantitative data needed to assess our entire national science and technology effort. It deals principally with changes in the support of innovation in the United States and other major developed nations and with the role of research and development in innovation. NSF also supported various reports on scientific manpower. For example, the *Summary Report, 1975 Doctorate Recipients from United States Universities*, published by the National Academy of Sciences/National Research Council, showed that the proportion of science and engineering doctorates awarded to women continues to increase. It stood at over 15 percent in fiscal year 1975, compared to 14 percent in 1974 and 7 percent in 1965.

NSF's planning and evaluation program also conducts science planning and policy analyses of issues of special concern to the NSF Director and to the National Science Board, as well as evaluations of selected NSF programs. Studies in 1976 concentrated heavily on NSF's peer review system for evaluating proposals. The Foundation also initiated a series of regional forums, which provide increased opportunities for scientific, professional, and citizen participation in Foundation program planning.

NSF's science information program fosters the interchange of information among scientists in the United States and with those in foreign countries, stimulates services leading to more effective dissemination of information, and supports the development of improved methods of making science information readily available.

During this past fiscal year, information exchange and joint activities were arranged in bilateral agreements between U.S. information services and similar groups from India, Japan, the Soviet Union, and Egypt. On a global scale, the Foundation represented the United States at meetings of the Office of Science and Technology of the United Nations,

UNISIST, UNESCO, and at the Conference on National and Regional Planning for Scientific and Technical Information Systems and Services in the Arab countries. In addition, a variety of research projects, reports, and workshops encouraged greater effectiveness in the transfer and use of scientific information. Over 1,000 copies of an *Innovation Guide* for the publishing industry were distributed to interested parties. An experiment initially supported by NSF in four California public libraries to provide searching services of scientific and technical information data bases has spread without further support to nine additional large public libraries in other parts of the country.

As a result of the Foundation's international programs, cooperative scientific research projects, joint seminars, and exchange visits are carried out under bilateral arrangements with some 40 different countries. The Foundation also participates in the scientific and technical components of new Joint Commissions for Economic Cooperation, established by the Executive Branch to achieve national foreign policy objectives.

During 1976, 55 cooperative research projects involved more than 200 U.S. and Japanese scientists. U.S. experts also undertook joint work in electrometallurgy, chemical catalysis, and computer applications in management systems with Soviet specialists in more than a dozen projects. U.S.-owned excess foreign currencies in Poland, Pakistan, Egypt, and India supported other cooperative research efforts, and the Foundation also used these foreign currencies to have foreign scientific journals and monographs translated into English. In addition to bilateral activities, NSF supported U.S. participation in such multilateral activities as the International Council of Scientific Unions, the International Institute for Applied Systems Analysis, and the Pacific Science Association.

Table 10
Scientific, Technological, and International Affairs
Fiscal Years 1974, 1975, 1976
and Transition Quarter (July 1-Sept. 30, 1976)

(Dollars in Millions)

	Fiscal Year 1974		Fiscal Year 1975		Fiscal Year 1976		Transition Quarter	
	Number	Amount	Number	Amount	Number	Amount	Number	Amount
International Cooperative Scientific Activities	757	$ 6.27	719	$ 7.93	690	$ 7.53	224	$3.04
Science Information Activities	62	8.08	75	5.38	102	5.89	33	0.76
Science Assessment, Policy, and Planning	114	8.05	172	11.57	218	8.99	71	2.35
Total	**933**	**$22.40**	**966**	**$24.88**	**1,010**	**$22.41**	**328**	**$6.15**

Science Assessment, Policy, and Planning

Policy Research and Analysis

The policy research and analysis program is responsible for investigating and analyzing the magnitude and directions of scientific and technological research and its ability to meet the Nation's domestic needs and international commitments. Also, this program provides analytical support to various groups within the Executive Office of the President such as the Office of Management and Budget, the Council of Economic Advisers, the Domestic Council, and the Office of Science and Technology Policy.

Policy research and analysis aids in science and technology policy formulation through internal analyses and external studies of relevant existing and emerging national issues. These issues are roughly divided into six categories, with responsibilities assigned to the NSF working groups whose activities are described below.

The Effects of Public Policy on Science and Technology

In studies of public policies directed to social and economic goals that influence the science and technology environment, attention is directed towards better understanding of (1) the incentives government can use to stimulate socially desirable technological innovation in the private sector and (2) the incentives for technological innovation created by policies directed to other public concerns.

Projects supported during 1976 included:

- A review of the history of technological diffusion in hospitals to suggest a model of such diffusion. The model, now being developed further, should provide improved information about the Federal Government's increasing role in health care.

- A study completed under the Federal Council for Science and Technology to help Federal agencies set policies and procedures for repayment to the Government for its R&D expenditures that lead to profitmaking goods and services in the private sector.

Analysis of Emerging Science and Technology

The rapid development of science and technology raises such important issues as: (1) the adequacy of federally supported basic and applied science to meet national needs; (2) the adequacy of the science and technology base for Federal regulatory activity; (3) "spin-off impacts" of Federal science and technology programs; and (4) the adequacy of Federal mechanisms for monitoring the potential impacts of U.S. and foreign Government policies on the health of the domestic science and technology enterprise.

Projects supported during 1976 included:

- A series of reports titled *Halocarbons: Environmental Effects of Chlorofluoromethane Release/Effects on Stratospheric Ozone.* Supported by NSF in joint sponsorship with NASA, EPA, NOAA, and FAA, this series was prepared under the auspices of the National Academy of Sciences. It points to the need for selective regulation of chlorofluoromethane and evaluates the extent to which stratospheric ozone will be affected by man.
- An analysis of improved climatological information for agricultural decisionmaking, cosponsored by NOAA. This project will help determine the value of better climatological forecasts for agriculture.
- A case study in Boston examining the planning process underlying the national wastewater treatment facilities construction grants program administered by EPA.

The Analysis of International Science and Technology Policy

Analyses are made of: (1) the impact of international science and technology programs on the U.S. scientific community; (2) the impacts of international science and technology transfer, through Government and private channels, on the foreign partners; (3) appropriate institutional arrangements for U.S. involvement in international cooperative activities; and (4) the purpose and value of U.S. participation in the science and technology programs of international organizations.

Projects supported during 1976 included:

- A comparative study of past and proposed U.N. science conferences, highlighting lessons relevant for U.S. involvement in future U.N. conferences.
- A review of postwar U.S. policies toward the transfer of U.S. technology across national boundaries, entitled *Technology Transfer and U.S. Foreign Policy.* Results of this project are being used by NSF and the Departments of State and Commerce.

The Socioeconomic Effects of Science and Technology

Areas being investigated include: (1) the socioeconomic variables affecting technology policy options; (2) distribution of public versus private costs and returns from innovation; (3) effects of science and technology on the individual; and (4) effects of science and technology on productivity.

Projects supported during 1976 included:

- An assessment of the effects of technological change on the supply and demand of raw materials.
- Examination of how foreign subsidiaries and investment of U.S.-based firms spread U.S. technology abroad.

The Processes of Innovation and Their Management

Analyses are made of the incentives and roadblocks that influence innovation in science and technology. By comparing how various organizations use technological innovations, this program can help the Federal Government and private management improve their utilization of technology.

Projects supported during 1976 included:

- An assessment of the impact of rapid innovation on standardization and mass production in the automobile industry.
- A review of how State and local governments have introduced technological innovation in their services, and the factors that lead to their success or failure.

Policy Aspects of Energy, Resources, and Environment

Responsibilities in this area include analysis of (1) energy technology research; (2) environmental health issues related to energy; and (3) the relation of science and technology to renewable and nonrenewable resources.

Projects supported during 1976 included:

- A series of open workshops to promote discussion between government, industry, the general public, academia, and special interest groups on issues such as: "Public Participation in Energy Related Decision-making," "Legal and Institutional Problems of Energy Facility Siting," and "Institutional Alternatives for LMFBR Development and Commercialization."
- Independent studies on alternative fission reactor strategies for the United States, long-term energy alternatives for automotive propulsion, bioconversion, and alcohol fuel technology.

In addition to the extramural projects highlighted under the six categories noted above, in-house projects were also undertaken by program staff to analyze the scientific and technological aspects of national issues on the premise that a better understanding of such questions may improve Federal policies. The policy research and analysis program draws on the expertise of the basic and applied research programs within NSF, providing them in turn with access to information from the user agencies and with assistance in defining policy problems.

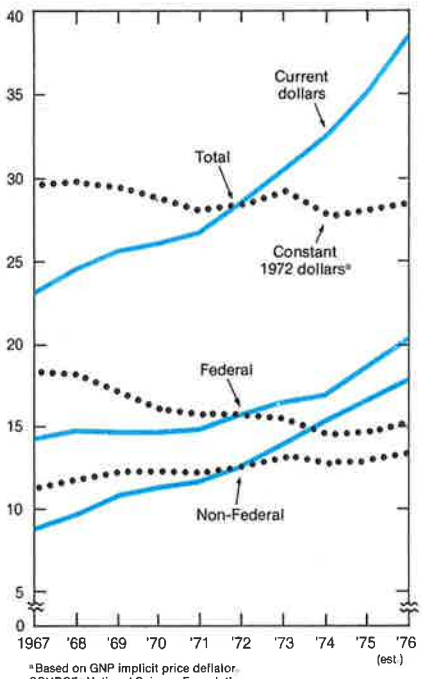
Science Resources Studies

The Foundation's program of science resources studies encompasses the collection, analysis, interpretation, and dissemination of data relating to the Nation's scientific and technological activities. The main objective of the program is the development of information for planning and policy formulation in the area of science and technology resources. The information developed through these studies is made available to a wide audience through publication of reports. Some representative examples of science resources studies carried out during the year are described below.

Periodic Studies of the Funding of Science and Technology

Expenditures for research and development in the United States are estimated at $38.1 billion in 1976, an 8-percent increase over 1975. For the first time in 3 years, total R&D funds are also expected to increase in terms of constant dollars—2 percent—assuming a 6-percent rate of inflation for 1976. In 1976 the Nation is expected to devote 2.2 percent of its gross national product to R&D activities. This ratio has declined steadily from its peak of 3.0 percent in 1964, primarily as a result of the slowdown in growth of Federal R&D spending. These and other data are published in *National Patterns of R&D Resources: Funds and Manpower in the United States, 1953-1976*, which contains analyses of the national R&D effort in terms of types of research and development, performer, and source of funds.

R&D funding trends: 1967-76



*Based on GNP implicit price deflator.
SOURCE: National Science Foundation

Data based on the President's Fiscal Year 1977 Budget indicate that Federal obligations for research and development are expected to total $23.5 billion, a record high and an increase of 8.6 percent over 1976. This growth is ahead of anticipated inflation, although in terms of constant dollars the estimated 1977 total is approximately 20 percent below that for 1967. Energy development and conversion is expected to be the leading growth area in Federal R&D funding for 1977, with obligations expected to increase by 24 percent over the previous year. Education, development of the science and technology base, and national defense also show growth well ahead of anticipated inflation. These and other data were published in preliminary form in the Science Resources Studies Highlights series. Two full analytical reports, *An Analysis of Federal R&D Funding by Function, Fiscal Years 1969-1977* and *Federal Funds for Research, Development, and Other Scientific Activities, Volume XXV*, are in preparation for publication early in fiscal year 1977.

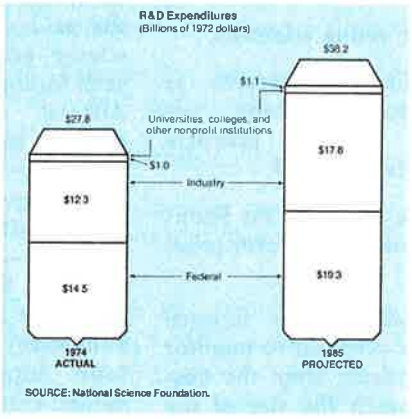
Preliminary data on 1975 industrial R&D funding showed that total R&D expenditures in the industrial sector were over $23 billion in 1975, an increase of 4 percent over the previous year's level. However, when measured in constant dollars, there was a 4-percent decrease between the two years. The Federal Government funded one-third of the total, four-fifths of the Federal share being concentrated in two industries, aircraft and electrical equipment. Total energy R&D spending increased by 15 percent to a level of $1.4 billion. Industry employed the full-time-equivalent of 360,000 scientists and engineers in January 1976, about the same number as a year earlier.

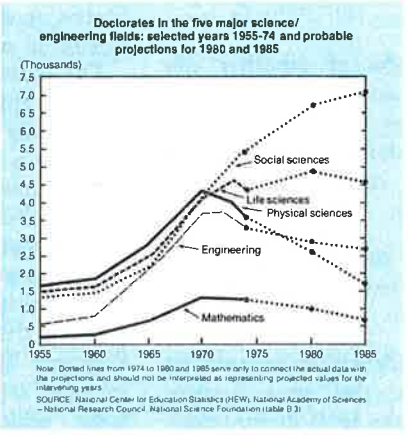
Periodic Studies of Scientific and Technological Manpower

The Foundation's Manpower Characteristics System, instituted in 1972, had produced by 1976 comprehensive data that makes possible a national appraisal of the employment, work activities, and professional characteristics of the scientific and engineering population. Estimates of the characteristics of U.S. scientists and engineers in 1974 were released in the Science Resources Studies Highlights series. A full analytical report, *U.S. Scientists and Engineers: 1974 Characteristics*, is in press. These reports present data describing a population of almost 2 million, 1.1 million of whom were engineers. Slightly less than 10 percent of the population were women. Racial minorities accounted for less than 5 percent of the population. The representation of both women and minorities was substantially greater among scientists than among engineers. The data also show that research and development was the principal work activity of scientists and engineers. Basic and applied research were dominated by scientists; development was the primary work activity of about one-third of the employed engineers.

Special Studies

During the year two special reports dealing with projections of science and technology resources were released. One, *R&D Funding Projections*, projected a 3-percent annual growth in constant dollar R&D spending between 1974 and 1985. Another, *Projections of Degrees and Enrollment in Science and Engineering Fields to 1985*, projected additions to the supply of scientists and engineers, with emphasis on doctorate production. The projections indicate that there will probably be an adequate supply of science and engineering doctorates during the next decade even though the ratio of science and engineering doctorate degrees to 30-year-olds, the traditional reference group, will decline to the level of the early sixties. Both reports describe in detail the methodology used.





To supplement the in-house projections, the Foundation announced a new program to support studies in the field of scientific and technical manpower forecasting. Proposals were invited in three categories: improvement of projection methodology, development of information needed to fill existing data gaps, and projections of science and engineering manpower supply and demand.

Two special studies dealing with academic faculty in science and engineering were completed during the year. One of these indicated that the proportion of young faculty (i.e., those who had held doctorates 7 years or less) in doctorate-level departments was expected to fall from 28 percent in 1976 to 25 percent by 1980, a level which nearly one-half of the department heads consider undesirable. The other study reported that more than four-fifths of the full-time doctorate faculty spent at least 20 percent of their time in research and that two-thirds of these had external, separately budgeted research support. Nearly a tenth, however, had research support in an area other than that in which they preferred to work. These studies were two of a series of Higher Education Panel Surveys conducted for the Foundation, the National Institutes of Health, and the U.S. Office of Education by the American Council on Education.

NSF Planning and Evaluation

Policy studies on Foundation-wide issues and concerns are carried out by both NSF staff and under contract for the use of the Director and the National Science Board in planning and policymaking. Studies originate from needs perceived by the Foundation and the science community and from requests made by the Office of Management and Budget and by the Congress.

The "steady state" of academic employment forecasts for the next two decades has occasioned a series of policy discussions concerning likely consequences for the health of science and possible approaches to mitigate negative effects. Two extramural awards have been made to assess the areas of voluntary early retirement and mid-career change opportunities for college and university faculty. The first of these studies reviews existing and newly collected

survey material on faculty age distribution by scientific field, including data relating to possible faculty interest in early retirement and mid-career changes. The second documents existing institutional practices in universities, government, and industry relating to early retirement and mid-career change. Together the studies will identify a series of options for university and college faculty, paying special attention to costs and benefits for both individuals and institutions.

Internal staff studies have included an analysis of NSF's Science Education programs, relating them to areas of national needs and identifying the NSF role in science education in the context of the larger role of Federal, State, and local government.

A related extramural study was designated to assist the Foundation by devising ways to utilize existing information resources both within NSF and in other science agencies for policy analyses. The object of the research is to develop a formalized description of the research system that will serve as a framework for relating disparate data sources and organizing data in ways most useful for discussions and analyses of science policy issues.

Concern with the processes and consequences of peer review has come to the fore in the past year—both in Congress and in the scientific community. The Foundation has launched three major studies in this area: an award to the National Academy of Sciences to compile a detailed description of the way the NSF peer review system works; a survey of the attitudes toward the functioning of peer reveiw held by proposal reviewers and by recent applicants for NSF funding; and a series of studies related to peer review as part of the Congressional studies mentioned below.

In 1975 oversight hearings on peer review, a number of issues were raised which the House Subcommittee on Science, Research, and Technology felt required more extensive study and analysis. To this end the Subcommittee directed the National Science Board to study eight specific issues, as follows:

- Support of innovative research.
- Support of young scientists.
- The funding of research at undergraduate-teaching institutions without graduate departments (colleges).
- The extent to which the Foundation should rely on peer panel review.
- Establishment of an internal Foundation program to monitor problems arising from the mismatch between the size of the scientific community and the amount of Foundation funds available for support of that community.
- The question of whether the National Science Foundation should have formal procedures for considering appeals of decisions made on award applications.
- The effects of publication of the list of reviewers used by the Foundation.
- Further information concerning effects on the peer review system of the level of confidentiality in which peer reviewers' names and verbatim comments are held.

In developing responses to these questions the Foundation has prepared a detailed analysis of the hearings, awarded eight extramural study contracts, and initiated a series of internal staff studies to deal with the Subcommittee's questions—e.g., a study that looks at innovations and scientific reputations in four fields of science (chemistry, astronomy, mathematics, and earth science).

To meet the Congressional mandate to facilitate public participation in the formulation, development, and conduct of NSF's programs, policies, and priorities, the National Science Board in 1976 initiated a program of regional public meetings designed to encourage the expression of views by the general public on scientific and science education issues. The first such forum was held in June 1976 in Atlanta. Approximately 200 individuals representing a broad section of society—including business, State and local governments, public interest groups, citizen organizations, and academia—from seven States (Alabama, Florida, Georgia, Mississippi, North and South Carolina, and Tennessee) were in attendance. The four topics discussed—energy, natural systems, food systems, education, and knowledge—were selected by a planning group that was representative of the Southeastern United States. A second forum was held in Seattle in early November 1976.

The Foundation regularly conducts in-depth studies of major programs to provide the NSF Director with information on program results, impact, effectiveness, and conformance with legal authority. In fiscal year 1976 Battelle Columbus Laboratories completed an evaluation of three of the five major biome studies conducted as part of the International Biological Program. The biome programs were intended to increase understanding of large ecological systems through integrated research efforts. Battelle's evaluation focused on the extent to which the results were integrated or integrable. The evaluation concluded that the biomes were a well managed and balanced effort. However, because research results are still being produced, this evaluation did not attempt to assess the primary product of the biome programs, increased understanding of the ecosystems. Two additional program evaluations, those of the International Decade of Ocean Exploration

and science information activities, were under way during the year and are scheduled for completion in early fiscal year 1977. In another area, attention was given to studies of the published literature as a means of assessing research output. This resulted in a monograph, *Evaluative Bibliometrics*, completed under a contract with Computer Horizons.

The Foundation continued to support and use the analytical and advisory services of the National Academy of Sciences' Committee on Science and Public Policy (COSPUP) and the National Academy of Engineering's Committee on Public Engineering Policy (COPEP).

Science Information Activities

The science information programs support activities to improve the accessibility and increase the use of scientific and technical information. During 1976, projects were carried out in four program areas: information science, access improvement, user requirements, and management studies and coordination.

Information Science

Information science is an emerging field oriented toward understanding the processes of information transfer. The Foundation supports theoretical and conceptual research in this field, building upon advances in related disciplines such as behavioral science, computer science, and linguistics. Particular attention is given to research for accessing knowledge about more useful and effective ways of applying new technologies for improving access to and use of information.

During 1976 the program continued to support work to enhance the theoretical foundations of information science. Case Western Reserve University explored the possibility of integrating various competing paradigms into a general theory of information transfer. New York University was given further support to investigate the informational properties of scientific texts; in particular, the repeated information structures of science language by subdiscipline were investigated to provide the basis for natural language processing.

In the area of information systems evaluation, results from work supported at Ohio State University led to a general simulation capability for research in the underlying methodology of system performance measures. Further support in 1976 extended this simulation capability from the basic computer configuration to such areas as the efficiency of data base structures relative to the underlying computer system and to the cost allocation of computer resources to information system services.

The information science program continued its joint support of networking problems with the Foundation's computer science program. One project, a large-scale simulation and gaming effort under the auspices of EDUCOM, involves some 20 academic institutions. Exploration of the economics of computer communications networks is the object of a long-term project at Stanford University. Two other projects, at the Massachusetts Institute of Technology and at the University of Illinois, are intended to ease the problems of access by users of on-line, interactive science information network systems.

Access Improvement

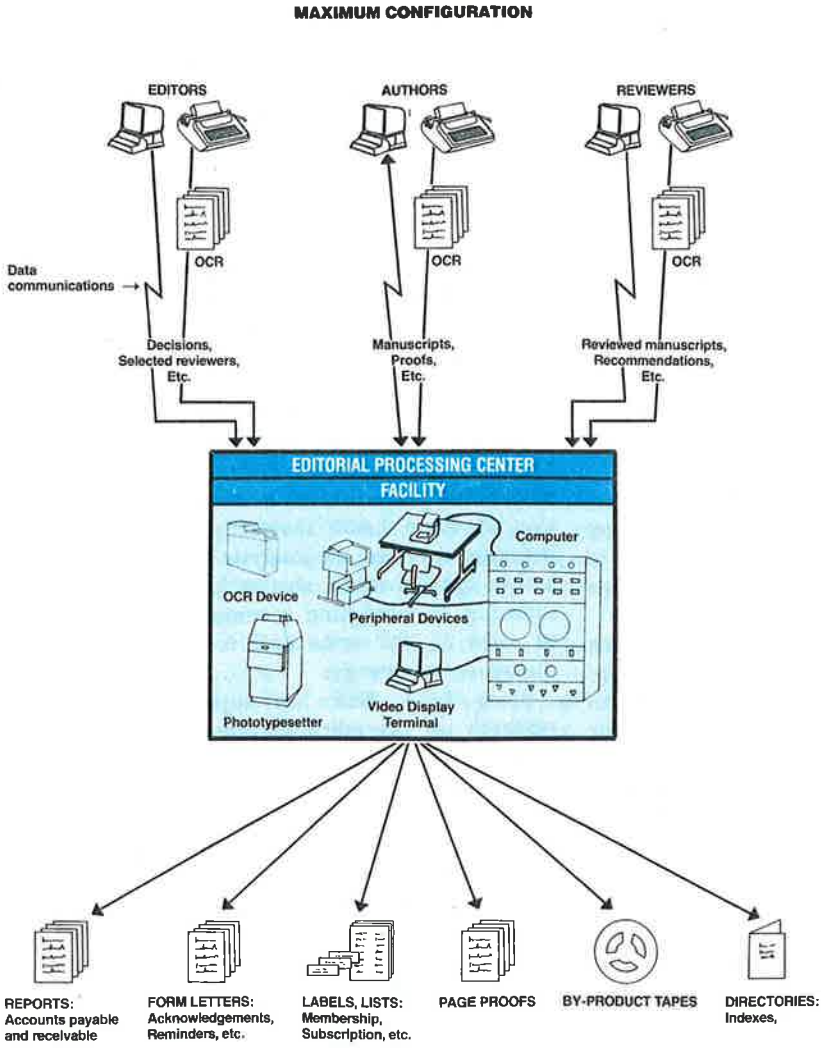
The access improvement program supported 33 projects to improve the transfer of scientific information from originators to users. One such project continues to survey technical and organizational innovations in scientific and technical communication, and results are regularly distributed to more than 1,000 persons in position to take advantage of such innovations. Other projects were concerned with effectiveness of abstracting and indexing services in providing access to scientific and technical literature. Projects completed this year resulted in a description of some 1,800 abstracting and indexing services, an analysis of the article overlap in 14 abstracting and indexing services, and a compilation of some 26,000 terms used to index literature on energy.

Since 1973, NSF has supported research on the editorial processing center (EPC), a mechanism to help small journal publishers use computer technology to create the primary record of scientific accomplishments. Tests conducted with a small-scale EPC prototype showed the feasibility of several methods for processing manuscripts. A second series of tests, initiated in 1976, uses a more advanced prototype and will lead to a full-scale operational demonstration.

Also in 1976, a test facility for the experimental investigation of electronic information exchange was completed. Several small research communities will experiment next year with this innovative method of communication.

User Requirements

The user requirements program continued to fund research designed to encourage more effective use of scientific and technical information by scientists and engineers. This program sponsored empirical studies, analyses, and field experiments on



Primary publishing. A prototype Editorial Processing Center, being tested as a prelude to a full-scale demonstration, is a computer-based system with potential for faster and more economical publishing for scientific journals. The technologies employed in an EPC may include optical character recognition (OCR), text editing, inventory control, and photocomposition.

the development of more user-responsive services. Other projects were aimed at improving the organizational conditions affecting the use of scientific and technical information.

The influence of information use on the conduct of research and the management of research and development was a principal area of concern during 1976. One study identified the information-use habits of highly productive researchers and suggested how to design new information products to fill this group's needs.

Several technology forecast projects in 1976 attempted to find the effects of information/communication technology on the delivery, cost, and use of scientific and technical information. One study assessed the feasibility of electronic storage and delivery of engineering handbook data and concluded that this would require computerized design aids. Another study determined that technology will not be the prime inhibiting factor in the improvement of information service.

Management Studies and Coordination

Management studies continued to support the collection and analysis of economic data on the production, distribution, and use of scientific and technical information. Studies were initiated on the interaction of law, economics, and technology in the use of copyrighted materials; the impact of photocopying on libraries and publishers; the development of models to predict and assess use of library materials; and methods to weigh the costs and benefits of the different kinds of information services.

Two reports from the first year's research on statistical indicators of scientific and technical communication were recently completed. One provides the data compiled and a statement of research undertaken, resources examined, and methods used for projection and estimation; the second report provides an analysis of the data.

Support for communication and coordination among U.S. science information services was continued, as was the interchange of scientific information with international organizations. During 1976 NSF arranged a series of meetings among managers of Federal scientific and technical information services on such topics as Federal and private sector problems in scientific and technical information, international information policy, and directions for future research and development.

The Foundation also participated in bilateral international science information activities during the year. Cooperative activities were carried out with the Soviet Union, Japan, Mexico, and Egypt.

Through an exchange agreement, the Government of India will help set up a seminar on information sources related to energy, environment, and natural resource problems, and arrange for a seminar the following year on the education of science information specialists. NSF continued to serve as the focal point for UNESCO's UNISIST activities in the United States. With support from the Foundation, the National Academy of Sciences continued its review of U.S. participation in international science information programs and worked toward establishing U.S. goals.

International Cooperative Science Activities

NSF has sole, or Executive Agency, responsibility for binational agreements relating to international cooperation in science between the United States and 14 foreign countries, and major involvement with seven other agreements. Research conducted under these agreements obtains for scientists in the United States the benefits of international collaboration, including exchanges of information and access to unique talents and facilities. For example, under the U.S.-Italy Cooperative Science Program, NSF assisted in the support of a joint study of the dramatic physicochemical changes that occur in the lungs of newborn mammals. The experimental concepts came from Italy and were refined in the United States. And under a cooperative arrangement with the Soviet Union, both countries have benefited from joint projects in the field of electrometallurgy. The Soviets are advanced in extractive metallurgy and in the techniques of reduction, purification, and casting; U.S. expertise lies in materials science and materials engineering.

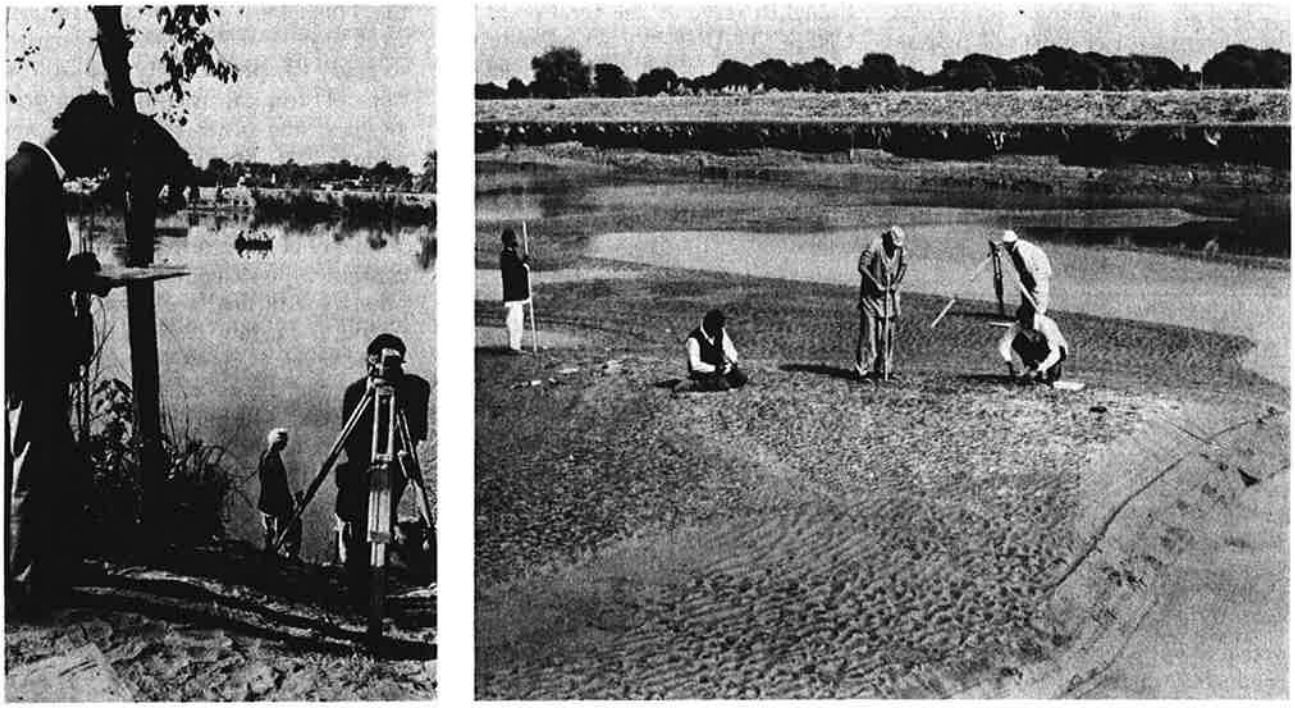
Each bilateral agreement has its own modes of cooperation, suited to the needs of the United States and its partner nations. The commonest forms are cooperative research projects, seminars, and the visits of scientists to teach or perform research in the other country.

The U.S. Government also has agreements with several countries, most of them in the Middle East, for economic cooperation. NSF continues to contribute to the programs outlined by the several Joint Commissions for Economic Cooperation that were established under these agreements. For example, on February 29, 1976, NSF agreed to assist, on a reimbursable basis, Saudi Arabia to establish a National Center for Science and Technology (SANCST). SANCST, a central science agency, will enhance Saudi Arabia's ability to use science and technology for economic and social development. NSF has established a Joint Commission Staff to serve as a principal channel of communication on Joint Commission programs between the Foundation and other organizations. NSF also coordinates program evaluation to assure benefits to science in the United States and support for the objectives of the Joint Commission agreements.

The Foundation continues to seek opportunities for international cooperation in selected regions of the world, outside the framework of formal agreements. In Latin America these opportunities have involved 29 activities in six "nonagreement" countries. In 1976 a new program made seven awards in cooperation with four East Asian countries: Thailand, Malaysia, Indonesia, and the Philippines. U.S. scientists will work with their East Asian colleagues to study the productivity and utilization of tropical forests, equatorial swamps, and other resources of the region that are subject to severe ecological stress.

Under an award to the National Academy of Sciences, the Foundation continued to support exchanges of scholars with the People's Republic of China. From July 1975 to September 1976, seven U.S. delegations visited China for discussions with Chinese colleagues, which they subsequently reported to the U.S. scientific community. The fields of interest included insect control, solid state physics, pure and applied mathematics, wheat studies, the Liaoning earthquake, steroid chemistry, and biochemistry. Eight Chinese delegations visited the United States. They represented the following technical areas: petrochemical industry, industrial automation, earthquake engineering, tumor immunology, agricultural mechanization, natural gas, environmental sciences, and interdisciplinary studies. Other awards to the Academy enabled the United States to participate in international scientific organizations, including the International Institute for Applied Systems Analysis and the International Council of Scientific Unions.

Under the special foreign currency (SFC) programs, NSF can use U.S.-owned local currencies instead of dollars in several countries. These funds, which must be used abroad, are declared by the Department of the Treasury to be in excess of the immediate needs of the U.S. Government. The SFC research and related activities program funds collaborative science projects involving U.S. scientists in Egypt, India, Pakistan, Poland, and Tunisia. Engineers of Colorado State University were able to test classical theories of flow and sedimentation in alluvial channels by working with colleagues of the Water and Power Development



Water research. As part of a U.S.-Pakistan joint research project, scientists (left) meter the water surface level of a Link Canal and take a soil core (right) to determine particle size of bottom sediments. The Link Canals, built to redistribute scarce water among Pakistan's rivers, are part of one of the world's most ambitious water development projects. Their size and variety make them valuable for research on the design of modern irrigation channels. (Photos by Kahlid Mahmood/George Washington University.)

Authority in Pakistan, where binational teams had access to the celebrated Link Canals of the Indus Valley for collecting their data. In Egypt, local currencies were used to fund projects in historical geology, nutrition, the improvement of science teaching, and the physiological adaptation of large mammals to desert conditions. In Egypt and in India, local currencies are used to fund the U.S. portions of projects designated by the Joint Commissions to be of high priority to the participating countries.

The SFC science information program procures translations into English of foreign technical publications. Those translations are requested by various U.S. Government agencies and are made available to non-government scientists.

Because of its broad legislative authority and its professional contacts with the U.S. scientific community, the Foundation sometimes responds to requests to manage programs that are authorized and funded by other U.S. Government agencies. One example is the Scientists and Engineers in Economic Development (SEED) program, operated by NSF for the Agency for International Development. In 1976 the SEED program supported teaching and research activities of U.S. scientists in 13 different countries of Africa, Asia, and Latin America. Among the subjects studied were energy resources in Pakistan, child nutrition and family planning attitudes in Kenya, forest insect pests in Chile, and the natural resources of the Amazon basin.

The international travel support program has enabled U.S. scientists to attend international scientific meetings, obtain or exchange information on basic research, and cooperate in international scientific activities. Approximately 450 international travel awards were made during 1976.

Science studies undertaken during the past year to develop and widen the international role of NSF are continuing, with initial emphasis on establishing methodologies to evaluate the Foundation's international programs. A related program, dealing with selected transnational issues of importance to the United States, will help provide policymakers with information for decisionmaking on transnational problems. It will also improve the application of research and other scientific activities to these problems.

Bilateral Science and Technology Agreements
Number of Approved Activities in FY 1976 and the Transition Quarter (July 1 to Sept. 30, 1976)

Country	Visiting Scientists: U.S. FY 1976	U.S. TQ	Foreign FY 1976	Foreign TQ	Seminars FY 1976	Seminars TQ	Cooperative Research Projects FY 1976	Cooperative Research Projects TQ
Argentina	—	—	—	—	1	—	3	2
Australia	13	7	—	—	7	—	11	8
Brazil	2	1	—	—	—	—	10	—
Rep. of China	12	3	—	—	3	2	12	3
France	19	2	16	—	—	—	5	1
Hungary	8	—	—	—	—	—	4	1
India	19	4	16	4	—	—	—	—
Italy	20	1	—	—	3	—	6	3
Japan	8	2	3	1	25	7	21	11
Mexico	3	—	—	—	2	—	8	5
New Zealand	—	—	1	—	2	—	—	—
Romania	1	—	6	—	3	1	5	—
Spain	—	—	14	—	—	—	16	1
U.S.S.R.	24	5	—	—	6	1	57*	2*
Total	129	25	56	5	52	11	158	37

* Includes awards made by other NSF components under U.S.-U.S.S.R. Joint Commission on Science and Technology.

Special Foreign Currency Program
Summary of Projects by Country in FY 1976 and Transition Quarter

Country	Research Grant Awards FY 1976	Research Grant Awards TQ	Travel Grant Awards FY 1976	Travel Grant Awards TQ	Active Translation Projects Contracts FY 1976	Active Translation Projects Contracts TQ
Burma	0	0	0	0	1	1
Egypt	12	1	3	2	2	2
India	1	1	30	2	2	2
Pakistan	2	1	9	1	1	1
Poland	8	2	29	4	1	1
Tunisia	1	0	0	0	1	1
Total	24	5	71	9	8	8

U.S.-U.S.S.R. and East Europe Academy Exchange Programs
Visits Each Way Funded During FY 1976

Country	United States Scientists	United States Man-Months	Foreign Scientists	Foreign Man-Months
U.S.S.R.	44	131	32	82
Bulgaria	20	27	6	25
Czechoslovakia	17	56	11	55
Hungary	10	36	14	35
Poland	18	43	5	40
Romania	8	26	6	25
Yugoslavia	12	36	8	35
Germany	5	5	5	5
Total	134	360	87	302

Appendix A

National Science Board, NSF Staff Advisory Committees and Panels

NATIONAL SCIENCE BOARD

Terms Expire May 10, 1978

W. GLENN CAMPBELL, Director, Hoover Institution on War, Revolution, and Peace, Stanford University
T. MARSHALL HAHN, JR., President, Georgia-Pacific Corporation, Portland, Oreg.
ANNA J. HARRISON, William R. Kenan, Jr., Professor of Chemistry, Mount Holyoke College
WILLIAM H. MECKLING, Dean, The Graduate School of Management, The University of Rochester
WILLIAM A. NIERENBERG, Director, Scripps Institution of Oceanography, University of California, San Diego
*RUSSELL D. O'NEAL (Vice Chairman, National Science Board), Consultant, KMS Fusion, Inc., Ann Arbor, Mich.
JOSEPH M. REYNOLDS, Boyd Professor of Physics and Vice President for Instruction and Research, Louisiana State University
CHARLES P. SLICHTER, Professor of Physics and in the Center for Advanced Study, University of Illinois at Urbana-Champaign

Terms Expire May 10, 1980

JEWEL P. COBB, Dean and Professor of Biology, Douglass College, Rutgers-The State University of New Jersey
*NORMAN HACKERMAN (Chairman, National Science Board), President, William Marsh Rice University
W. N. HUBBARD, JR., President, The Upjohn Company, Kalamazoo, Mich.
SAUNDERS MAC LANE, Max Mason Distinguished Service Professor of Mathematics, University of Chicago
GROVER E. MURRAY, University Professor, Texas Tech University Complex
*DONALD B. RICE, JR., President, Rand Corporation, Santa Monica, Calif.
L. DONALD SHIELDS, President, California State University, Fullerton
*JAMES H. ZUMBERGE, President, Southern Methodist University

Terms Expire May 10, 1982

RAYMOND L. BISPLINGHOFF, Vice President for Research and Development, Tyco Laboratories, Inc., Waltham, Mass.
LLOYD M. COOKE, Corporate Director-Community Affairs, Union Carbide Corporation, New York, N.Y.
HERBERT D. DOAN, Chairman, Doan Resources Corporation, Midland, Mich.
JOHN R. HOGNESS, President, University of Washington
WILLIAM F. HUEG, JR., Professor of Agronomy and Deputy Vice President and Dean, Institute of Agriculture, Forestry, and Home Economics, University of Minnesota, St. Paul
MARIAN E. KOSHLAND, Professor of Bacteriology and Immunology, University of California, Berkeley
ALEXANDER RICH, Sedgwick Professor of Biophysics, Department of Biology, Massachusetts Institute of Technology
(Vacancy)

* Member, Executive Committee

Member, Ex Officio

*RICHARD C. ATKINSON (Acting Chairman, Executive Committee), Acting Director, National Science Foundation, Washington, D.C.

VERNICE ANDERSON, Executive Secretary, National Science Board, National Science Foundation, Washington, D.C.

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Director, (Acting), Richard C. Atkinson
Deputy Director, (Acting), Edward C. Creutz
Director, Office of Equal Employment Opportunity, Herbert Harrington, Jr.
General Counsel, Charles H. Herz
Deputy General Counsel, Maryann B. Lloyd
Director, Office of Government and Public Programs, Theodore W. Wirths
Deputy Director, Office of Government and Public Programs, Jack Kratchman
Associate Director for Public Programs, Theodore D. Drury
Head, Congressional Liaison Branch, Patricia E. Nicely
Head, Public Information Branch, Jack Renirie
Head, Communications Resource Branch, Bruce R. Abell
Head, Community Affairs Branch, R. Lynn Carroll
Director, Office of Planning and Resources Management, Jack T. Sanderson
Deputy Director, Office of Planning and Resources Management, Walton M. Hudson
Audit Officer, Audit Office, Robert B. Boyden
Head (Acting), Budget Office, Thomas Ryan
Head, Evaluation Staff, Harry J. Piccariello
Head, Planning and Policy Analysis, L. Vaughn Blankenship
Head, Programming Office, Syl McNinch, Jr.
Head, Program Review Office, Lewis P. Jones
Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences, Robert E. Hughes
Deputy Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences, Edward P. Todd

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Appendix B

Patents and Inventions Resulting from Activities Supported by the National Science Foundation

During fiscal year 1976 and the transition quarter, the Foundation received 186 invention disclosures and made rights determinations in 40 inventions. The determinations, made in accordance with NSF Patent Regulations, included decisions to dedicate the inventions to the public through publication in 10 cases, to transfer rights to other interested Government agencies in 7 cases, to permit retention of rights by the grantee or inventor in 22 instances, and acquisition of rights by NSF in one case. At the end of the fiscal year NSF had entered into two additional Institutional Patent Agreements for a total of 13, under which 23 inventions were selected for exploitation. Licenses were received by the Foundation under four patents and 67 patent applications filed by grantees and contractors who had been allowed to retain principal rights in their inventions.

The following U.S. Patents issued from research supported by the Foundation:

No.	Title	Institution
3,892,839	Process for Forming Nitrosyl Tetrafluoroborate	Massachusetts Institute of Technology
3,895,361	Method and Apparatus for Reliably Parallel Self-Shifting Information in a Plasma Display/Memory Panel	University of Illinois
3,902,096	Method of and Apparatus for Exciting Luminescence in a Cathode Ray Tube Having an Image Screen Composed of a Material that is Both Cathochromic and Cathodoluminescent	Massachusetts Institute of Technology
3,902,848	Liquid Chromatography Detector and Method	Arizona State University
3,902,994	High Gradient Type Magnetic Separator with Continuously Moving Matrix	Massachusetts Institute of Technology
3,904,501	Fluorine Plasma Synthesis for Carbon Monofluorides	Massachusetts Institute of Technology
3,911,315	Cathode Ray Tube Whose Image Screen is both Cathodochromic and Fluorescent and the Material for the screen	Massachusetts Institute of Technology
3,916,905	Method and Means for the Repair of Severed Peripheral Nerves	University of Cincinnati
3,921,445	Force and Torque Sensing Method and Means for Manipulators and the Like	Stanford Research Institute
3,922,299	Vinylic Substitution Reactions	University of Delaware
3,932,592	Process for Preparing Cathodochromic Sodalite Having Enhanced Coloration Properties and a Cathode Ray Tube Employing Same	Massachusetts Institute of Technology
3,934,192	Method of Detection of Ions in Solution that are Susceptible to an Applied Force Field and Apparatus Therefor	Massachusetts Institute of Technology
3,934,922	Aerodynamic Drag Reduction Devices for Surface Vehicles	Aerovironment
3,935,457	The Production of Radiation-Induced Thermally Activated Current Devices by Selective Purification of Dielectric Solid Material	University of Wisconsin
3,935,592	Recording Instrument Adapted for Use in Remote Unattended Locations	Massachusetts Institute of Technology

3,944,732	Methods of Improving the Sensitivity of an Acoustically Scanned Optical Imaging Device	Stanford University
3,946,381	Graphic System Apparatus Utilizing Plasma Display/ Memory Devices with Direct Electrical Read-Out	University of Illinois
3,947,622	Vacuum Insulated AC Superconducting Cables	Massachusetts Institute of Technology
3,949,320	Miniature Crystalline Laser	Massachusetts Institute of Technology
3,950,789	Dry Ice Cooling Jacket	Kansas State University
3,951,689	Alkali Metal/Sulfur Cell with Gas Fuel Cell Electrode	Ford Motor Co.
3,952,880	Force and Torque Sensing Method and Means for Manipulators and the Like	Stanford Research Institute
3,954,585	Synthesis of Trifluoromethly-Substituted Compounds	Massachusetts Institute of Technology
3,961,102	Scanning Electron Microscope Fabrication of Optical Gratings	Cornell University
3,961,997	Fabrication of Polycrystalline Solar Cells on Low-Cost Substrates	Southern Methodist University
3,962,586	Sensitization of Radiothermoluminescence in Dosimetry Grade LiF by Simultaneous Appealing and Ultraviolet Illumination	University of Wisconsin
3,962,706	Data Processing Apparatus for Highly Parallel Execution of Stored Programs	Massachusetts Institute of Technology
3,963,698	Alkylations Employing In Situ Generations of Diazoalkane Alkylation Reagents	Massachusetts Institute of Technology
3,963,858	High Voltage Electrical Insulator	Massachusetts Institute of Technology
3,964,273	Compact Absorption Refrigeration Apparatus	Arkla Industries
3,965,116	Multioxymacrocycles	University of California
3,966,492	Sodium Sulfur Battery or Cell with Improved Ampere-Hour Capacity	Ford Motor Co.
3,967,515	Apparatus for Controlling Vibrational Chatter in a Machine-Tool Utilizing an Updated Synthesis Circuit	Purdue University
3,970,474	Method and Apparatus for Electrochemical Generation of Power from Carbonaceous Fuels	Stanford Research Institute
3,973,167	Spark Source with Electronic Switching Tubes	University of Wisconsin
3,976,503	Process for Recharging Secondary Batteries	Ford Motor Co.
3,980,076	Method for Measuring Externally of the Human Body Magnetic Susceptibility Changes	Stanford University
3,983,398	Method and Apparatus for X-Ray or Gamma-Ray 3-D Tomography using a Fan Beam	Stanford University
3,983,507	Tunable Laser Systems and Method	Cornell University

Appendix C

Financial Report for Fiscal Year 1976

(In Thousands of Dollars)

Salaries and Expenses Appropriation		
Fund Availability		
Fiscal year 1976 appropriation	$711,250	
Unobligated balance carried forward from fiscal year 1975	4,868	
Deferrals carried forward from fiscal year 1975	20,000	
Adjustments of prior year costs	2,803	
Fiscal year 1976 availability		$738,921
Obligations		
Mathematical and physical sciences, and engineering:		
Mathematical sciences	$17,257	
Computer research	13,216	
Physics	45,171	
Chemistry	34,650	
Engineering	35,848	
Materials research	46,123	
Subtotal, mathematical and physical sciences, and engineering		$192,265
Astronomical, atmospheric, earth, and ocean sciences:		
Astronomical sciences	$48,635	
Atmospheric sciences	44,527	
Earth sciences	27,121	
Ocean sciences	47,082	
U.S. Antarctic research program	48,585	
Arctic research program	[1]3,621	
Subtotal, astronomical, atmospheric, earth, and ocean sciences		$219,571
Biological, behavioral, and social sciences:		
Physiology, cellular and molecular biology	$43,694	
Behavioral and neural sciences	19,689	
Environmental biology	26,838	
Social sciences	[1]18,814	
Subtotal, biological, behavioral, and social sciences		$109,035
Science education:		
Science manpower improvement	$24,882	
Science education resources improvement	24,325	
Science education development and research	10,932	
Science and society	2,342	
Subtotal, science education		$62,481
Research applied to national needs:		
Resources	$15,201	
Environment	26,982	
Productivity	24,108	
Intergovernmental science and R&D incentives	4,336	
Exploratory research and technology assessment	1,400	
Subtotal, research applied to national needs		$72,027
Scientific, technological, and international affairs:		
International cooperative scientific activities	$7,529	
Science information activities	5,895	
Science assessment, policy, and planning	8,986	
Subtotal, scientific, technological, and international affairs		$22,410
Program development and management		$42,226
Subtotal, obligations		$720,015
Administration deferrals carried forward to transition quarter		$10,000
Unobligated balance carried forward to transition quarter		$8,906
Total, fiscal year 1976 availability		$738,921
Special Foreign Currency Appropriation		
Fund Availability		
Fiscal year 1976 appropriation	$4,000	
Unobligated balance carried forward from fiscal year 1975	1,298	
Adjustments of prior year costs	4	
Fiscal year 1976 availability		$5,302

[1] $300,000/year Man-in-the-Arctic Program, transferred to the Biological, Behavioral, and Social Sciences Activity.

Obligations		
Special foreign currency activity:		
Research and related activities program	$4,163	
Science information program	239	
Subtotal, obligations		$4,402
Unobligated balance carried forward to transition quarter		$900
Total, fiscal year 1976 availability		$5,302
Trust Fund		
Fund Availability		
Unobligated balance carried forward from fiscal year 1975	$2,569	
Receipts from non-Federal sources	1,605	
Fiscal year 1976 availability		$4,174
Obligations		
Astronomical, atmospheric, earth, and ocean sciences:		
Kitt Peak National Observatory	$40	
Ocean sediment coring program	3,092	
Subtotal, astronomical, atmospheric, earth, and ocean sciences		$3,132
Gifts and donations		$4
Subtotal, obligations		$3,136
Unobligated balance carried forward to transition quarter		$1,038
Total, fiscal year 1976 availability		$4,174
Salaries and Expenses Appropriation		
Fund Availability		
Transition quarter appropriation	$167,555	
Unobligated balance carried forward from fiscal year 1976	8,906	
Deferrals carried forward from fiscal year 1976	10,000	
Adjustments of prior year costs	997	
Transition quarter availability		$187,458
Obligations		
Mathematical and physical sciences, and engineering:		
Mathematical sciences	$4,695	
Computer research	2,982	
Physics	10,563	
Chemistry	9,252	
Engineering	9,210	
Materials research	8,280	
Subtotal, mathematical and physical sciences, and engineering		$44,982
Astronomical, atmospheric, earth, and ocean sciences:		
Astronomical sciences	$12,321	
Atmospheric sciences	9,657	
Earth sciences	7,728	
Ocean sciences	8,919	
U.S. Antarctic research program	13,435	
Arctic research program	1,299	
Subtotal, astronomical, atmospheric, earth, and ocean sciences		$53,359
Biological, behavioral, and social sciences:		
Physiology, cellular and molecular biology	$11,995	
Behavioral and neural sciences	5,474	
Environmental biology	7,146	
Social sciences	5,113	
Subtotal, biological, behavioral, and social sciences		$29,728
Science education:		
Science manpower improvement	$535	
Science education resources improvement	321	
Science education development and research	2,601	
Science and society	200	
Subtotal, science education		$3,657
Research applied to national needs:		
Resources	$3,260	
Environment	6,383	
Productivity	6,355	
Intergovernmental science and R&D incentives	1,015	
Exploratory research and technology assessment	407	
Subtotal, research applied to national needs		$17,420
Scientific, technological, and international affairs:		
International cooperative scientific activities	$3,042	
Science information activities	759	
Science assessment, policy, and planning	2,348	
Subtotal, scientific, technological, and international affairs		$6,149
Program development and management		$10,518
Subtotal, obligations		$165,813

Unobligated balance lapsing from fiscal year 1976		$183
Administration deferrals carried forward to fiscal year 1977		$10,000
Unobligated balance carried forward to fiscal year 1977		$11,462
Total, transition quarter availability		$187,458

Special Foreign Currency Appropriation

Fund Availability

Transition quarter appropriation	$500	
Unobligated balance carried forward from fiscal year 1976	900	
Transition quarter availability		$1,400

Obligations

Special foreign currency activity:		
Research and related activities program	$690	
Science information program	321	
Subtotal, obligations		$1,011
Unobligated balance lapsing from fiscal year 1976		$5
Unobligated balance carried forward to fiscal year 1977		$384
Total, transition quarter availability		$1,400

Trust Fund

Fund Availability

Unobligated balance carried forward from fiscal year 1976	$1,038	
Receipts from non-Federal sources	1,302	
Transition quarter availability		$2,340

Obligations

Astronomical, atmospheric, earth, and ocean sciences:		
Ocean sediment coring program	$727	
Subtotal, obligations		$727
Unobligated balance carried forward to fiscal year 1977		$1,613
Total, transition quarter availability		$2,340

SOURCES: FY 1978 Revised Supplementary Budget Schedules to OMB.
FY 1978 Budget to the Congress—Justification of Estimates of Appropriations.

Appendix D

National Research Centers Contractors

Associated Universities, Inc. (AUI)
Gerald F. Tape, President

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David S. Heeschen, Director

AUI Member Universities:
Columbia University
Cornell University
Harvard University
The Johns Hopkins University
Massachusetts Institute of Technology
University of Pennsylvania
Princeton University
University of Rochester
Yale University

Association of Universities for Research in Astronomy, Inc., (AURA)
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Cerro Tololo Inter-American Observatory
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Kitt Peak National Observatory
Leo Goldberg, Director

AURA Member Universities:
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California Institute of Technology
University of California
University of Chicago
Harvard University
Indiana University
University of Michigan
Ohio State University
Princeton University
University of Texas at Austin
University of Wisconsin
Yale University

Cornell University
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National Astronomy and Ionosphere Center
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Harold D. Craft, Director, Observatory Operations, Arecibo, P.R.

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National Center for Atmospheric Research
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UCAR Member Universities:
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University of Arizona
California Institute of Technology
University of California
The Catholic University of America
University of Chicago
Colorado State University
University of Colorado
Cornell University
University of Denver
Drexel University
Florida State University
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University of Hawaii
Iowa State University
The Johns Hopkins University
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University of Maryland
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University of Nevada
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New York University
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Ohio State University
University of Okalahoma
Oregon State University
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Purdue University
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