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# National Science Foundation Annual Report 1977



*Cover:* Scanning electron micrograph of part of a fossil leaf (see page 70).



U.S. **National Science  
Foundation.**

**Twenty-Seventh Annual Report for Fiscal Year 1977**

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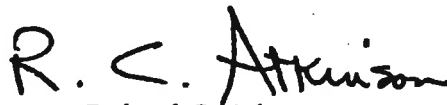
## Letter of Transmittal

Washington, D.C.

DEAR MR. PRESIDENT:

I have the honor to transmit herewith the Annual Report for Fiscal Year 1977 of the National Science Foundation for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,

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

Richard C. Atkinson  
*Director, National Science Foundation*

*The Honorable  
The President of the United States*



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# The Sweeping Impact of Science

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I am pleased to present the 27th Annual Report of the National Science Foundation. In reviewing the hopes and accomplishments of 1977, I am struck by increasing evidence that science and technology are linked ever more closely to the workaday contemporary world. While many scientific achievements appear to exert little immediate influence on our lives, others are obviously forcing extraordinary new powers on us—and demanding from us extraordinary responsibility.

Research, especially in the natural sciences, is gaining momentum as the Foundation nears three decades as the Federal Government's sole agency devoted to support for the complete spectrum of basic research. Aided by tremendous advances in experimental equipment and instrumentation, scientists working in the infinitesimal worlds of cells and atoms are leading us to new understanding of the essence of life and matter.

Physicists, for example, have found experimental evidence for what may well be a new kind of "quark," bringing to five the number of what are thought to be the most basic constituents of matter. At the same time, astronomers are accumulating data that may be relevant to the origins of life in the universe. By the end of 1977, a total of 40 different organic molecules had been detected in interstellar space. To some scientists, this evidence, gathered over the last few years, tends to diminish prior grave doubts that life may exist elsewhere in the universe.

In the greatly expanded field of experimental biology, scientists studying life at the molecular and cellular levels are now able to describe events in the earliest stages of plant, animal, and human existence. Developmental biologists are painstakingly identifying the very early biochemical events in the

critical process of fertilization. Molecular biologists are making parallel advances in unraveling the intricate structure and function of genes. The Foundation continues to support carefully safeguarded research with recombinant DNA—the technique that enables scientists to transplant component parts of genes from one species to another.

These separate scientific developments are posing questions that must be dealt with ethically and politically. They also pose serious challenges for science: If we can perceive the origin of life in the universe, will we have better clues to our own existence? Will knowledge of the fertilization process enable us to cope with population problems? And will the ability to manipulate genetic codes enable us to breed plants that can capture their own nitrogen and grow without fertilizer? Can we embark on "gene therapy" for disease?

The eventual answers to these and other questions challenging scientists may well come about through improved methodology. What one branch of science learns from another sometimes suggests a radically different approach in research. Also vital to progress in chemistry, physics, biology, and their multidisciplinary offspring are new mathematical concepts that make order out of seeming disorder. Such concepts lie at the heart of advances in the computer sciences, which for some time have been changing the way scientists perform experiments, process data, and develop models. The newest theories concerning the construction and programming of computers promise even more sweeping accuracy and productivity in all fields of science, particularly in dealing with complex tasks or subject matter.

The refinement of scientific instruments, their use in new ways, and new techniques combining several technologies continue to facilitate breakthroughs in many areas. High energy accelerators, for example, are now being employed to extend the uses of carbon-14 dating of ancient artifacts. Lasers are being used to induce and analyze chemical reactions, and spectrometers with greatly improved resolution are enabling chemists to study phenomena that take place in trillionths of a second. With the aid of better optical and radio telescopes, astronomers are now examining in detail nearby stars, our sun and its planets, as well as powerful X-ray sources a billion light-years away. In the study of materials, the combined use of Mossbauer spectroscopy and nuclear magnetic resonance is leading to new knowledge of the properties of superconducting materials.

Clearly, basic scientific research is in a highly dynamic stage. As always in the opening of new scientific vistas, however, our improved vision tells us only that while we have made remarkable progress, we still have much to learn. Some events of last year made this clear. While yielding up valuable secrets, nature nevertheless seemed determined to keep the upper hand, and exacted tradeoffs.

### Unbridled Nature

Certainly 1977 was a time in which the unbridled forces of nature were highly visible—and often destructive. What had seemed to some people like idle chatter about dwindling fuel supplies came abruptly home with the lowered thermostat and empty woodbox, as a bitterly cold winter gripped most of the United States and much of the world in an icy clasp. Although some scientists believed they had predicted the cold winter of 1976-77, the many processes affecting the weather are complex; it may be some time before such predictions become reliable. Moreover, our storehouse of knowledge contains nothing new in the way of technology to prevent cold winters—and only conventional technology to cope with it.

Last year's drought reinforced the lesson. It sharpened our awareness that abuse of the land and

seemingly capricious weather conditions are widening sand belts—turning fertile cropland into potential dustbowls and forests into tinderboxes. Like much of the rest of the world, the United States had to face problems of aridity, particularly in the Southwest and Far West. In the parched State of Georgia the corn crop loss shriveled production to a net loss of \$225 million. In California, forest fires devastated at least 150,000 acres more than usual.

How will we cope with desertification and drought? A better understanding of the mechanics of climate will be essential to long-range solutions. Last year, scientists using tree ring records to study ancient weather conditions found that, historically, major world droughts occur about every 20 years. This is in close correlation with sunspot activity, which suggests a new means for scientists to anticipate droughts, so that the Nation can prepare for them. The Foundation is also concentrating research on more immediate aspects of aridity, such as drought management in hard-hit areas.

Although these are starts, we are growing impatient at our continued vulnerability to natural catastrophes. Even if there was no major destruction by earthquakes last year, minor tremors continued to rattle windows and wrinkle meadows in expected and unexpected places. The scientific knowledge being developed will hopefully increase our ability to predict earthquakes, tidal waves, and hurricanes. Moreover, engineers have gone a long way in planning buildings that can withstand such upheavals. But controlling major natural phenomena is still far beyond our ken—and may always be so. As if in demonstration, in 1977 the Earth spewed forth a fountain of fire over our 50th State, causing at least one Hawaiian village to brace for an onslaught of molten lava—then only nipping at its abandoned outskirts. The eruption stopped of its own accord.

### Creative Synthesis

If we have far to go in managing such powerful forces, we nevertheless continue to explore their workings and to capitalize quickly on knowledge gained. A major determinant of our quality of life, the

creative synthesis of technology and nature is also essential to our social and economic progress. Peace and freedom, which now seem the possession or within the grasp of more people than ever before, can become bitter victories if industries grind down because of shortages or obsolescent equipment. Capital investment may partially determine the strength of any economy, but the most telling stimulus is probably the amount of innovation—often the direct result of scientific inquiry.

In the United States, science is presently being tapped to develop better sources of energy to feed the Nation's furnaces and find new material supplies to keep production levels high. Particularly at this time in our history, science is also challenged to meet pressing public needs to save time, money, and energy through better technologies and to increase our lagging productivity so that we can compete aggressively in an increasingly competitive world market. It is also challenged to provide jobs for an expanded work force.

Two economists recently categorized the relationship of research and development to economic prosperity. As pointed out in this space last year, Edward Denison of Brookings Institution found that "advances in knowledge" have been the biggest source of economic growth and productivity in the United States during the past four decades. Along other lines, Edwin Mansfield of the University of Pennsylvania examined 17 specific industrial innovations, estimating their returns to society as a whole and to the specific industries involved. The median societal rate of return on the R&D investment that produced the innovation was about 56 percent. The median rate of return to the industries was about 25 percent. This difference results because the social rate of return includes price reductions realized from the use of an innovation, as well as increased profits to the innovating firm. Consistently high social and private rates of return appear to more than justify the R&D investment. But the most interesting point is that the return tends to be higher for the Nation as a whole than for the particular industry involved.

The impacts of basic research on the quality of life are not so quantifiable, but are apparent in improvements in many walks of life—health,

environment, standard of living. Such benefits could be accelerated. One important task now facing society is to shorten the time lag between scientific discovery and its eventual application to public needs. Some incubation period, of course, has its value, giving us time to assess and plan for the multiple effects of technological changes. "Progress" is sometimes a mixed blessing, particularly in its immediate effect on employment. For more than 100 years, for example, technology in agriculture has been eliminating jobs and accelerating urban migration while at the same time improving food supplies. High-technology industries, on the other hand, are often job intensive, requiring highly trained manpower to design, improve, and maintain new products and processes. Unfortunately, the same person displaced from an eliminated job may lack the skills needed to step into a newly created one. This continues to be a serious problem in technological societies and one whose solution is not clear.

It is certain, however, that employment expansion will continue to be an attribute of technology-based fields. Despite competition from abroad, employment in U.S. science-dependent drug and electronic industries during the past two decades has approximately tripled. Developments in energy will bring further changes. In a survey of all U.S. scientists and engineers, the National Science Foundation last year found that 16 percent of the total are now working in jobs related in some way to energy.

Any increase in knowledge—from either basic or applied research—places a heavy responsibility on both scientists and nonscientists for setting goals. Since the strength of science in the United States depends upon an adequate supply of highly qualified teachers and researchers, the Foundation continues to help talented young men and women advance their science careers through fellowships and other financial aid. There is a new effort, moreover, to ensure that women, minorities, and the handicapped are given equal access to sound science education. This is complemented by NSF's continuing programs to improve the science literacy of as broad a public as possible, using the facilities of museums, the news media, and public forums.

We know that as a Nation we face major policy

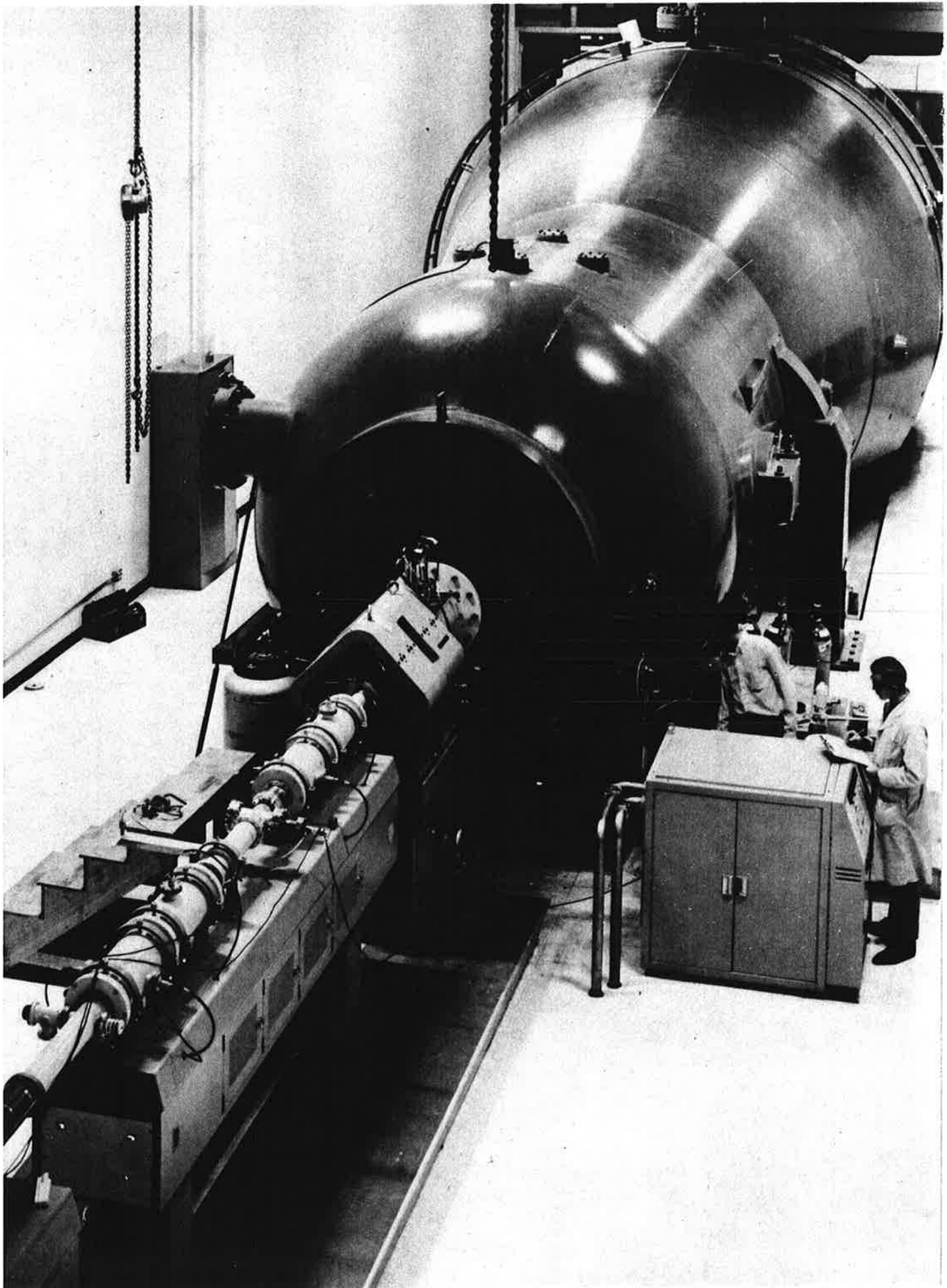
decisions regarding the future of our scientific enterprise. Our national security and well-being depend on our choices. We also face decisions on how to cooperate with other industrialized nations whose political goals we may or may not share . . . and how to extend our expertise to nations whose educational systems, research communities, and often political systems are still in formative stages. We have a strong national pride in what we have accomplished—aware

that our inventiveness in science and technology, given our free political system, has played an influential role in helping us gain industrial leadership. We seek to maintain that leadership—and our high standard of living. Ideally, our example will inspire the widespread creativity and hard work needed for science and technology to serve the interests of all mankind.

Richard C. Atkinson  
Director







# Mathematical and Physical Sciences, and Engineering



**R**esearch programs in the Mathematical and Physical Sciences, and Engineering have the objective of increasing our store of knowledge in these fields. Most of the research supported is basic in character, although some research is also supported with specific applications in mind. Pure mathematics, by most standards, is the epitome of the former, whereas research in the engineering, materials, and computer sciences includes examples of the latter.

The 44 research programs in the Mathematical and Physical Sciences, and Engineering operate primarily through the support of individual projects. Proposals are initiated by scientists and engineers who wish to answer specific scientific questions. Most proposals are submitted by academic institutions in the United States in behalf of these researchers.

Research proposals are reviewed by members of the "peer" community who are capable of understanding the intent of the research and the significance of the possible results. During 1977, the review process involved some 30,000 reviewers from all parts of the country and abroad in judging the merit of projects that had been proposed in the Mathematical and Physical Sciences, and Engineering. Most reviewers were from universities; however, many persons from government, industrial laboratories, and research organizations also participated. Successful proposals ul-

timately resulted in support for the research efforts of more than 5,000 scientists and engineers. In addition, more than 4,400 graduate students received an opportunity to work under the tutelage of some of the Nation's finest researchers. Since personal involvement is the best way to learn how to do research, this is a beneficial spinoff of the quest for new knowledge and represents an important investment for the future.

Although science and technology have made progress toward ameliorating some of the seemingly intractable problems of today's world, solutions to many of the longer term problems—such as those relating to energy and the environment—will depend on new knowledge resulting from research in the Mathematical and

Physical Sciences, and Engineering. For example, basic research in the chemistry of solar and fuel cells is an ongoing effort. Materials scientists are exploring the feasibility of using amorphous semiconductors as inexpensive materials for large-scale photoelectric solar energy conversion. Through the establishment of the National Research and Resources Facility for Submicron Structures, scientists throughout the Nation will be able to pursue research on ultraminiature electronic, magnetic, optical, and superconducting devices. A pilot research effort concerning oil recovery by surfactant flooding is being undertaken by some engineers. Theoretical work in thermoradiation, coupled with experimental results made available from shock tube tech-

**Table 1**  
**Mathematical and Physical Sciences, and Engineering**  
**Fiscal Years 1975, 1976, Transition Quarter**  
**(July 1-Sept. 30, 1976), and 1977**

(Dollars in Millions)

	Fiscal Year 1975		Fiscal Year 1976		Transition Quarter		Fiscal Year 1977	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Chemistry .....	828	\$ 32.73	832	\$ 34.65	220	\$ 9.25	881	\$ 40.23
Engineering .....	710	34.26	691	35.85	188	9.21	834	41.77
Physics .....	328	42.20	354	45.17	82	10.56	372	53.99
Materials Research .....	524	43.53	609	46.12	147	8.28	657	52.58
Mathematical Sciences .....	842	16.46	838	17.26	104	4.70	833	20.06
Computer Research .....	193	11.78	216	13.22	51	2.98	250	15.79
<b>Total .....</b>	<b>3,425</b>	<b>\$180.96</b>	<b>3,540</b>	<b>\$192.27</b>	<b>792</b>	<b>\$44.98</b>	<b>3,827</b>	<b>\$224.42</b>

SOURCE: Fiscal Years 1977, 1978, and 1979 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

nology, could lead to more efficient and environmentally compatible combustion processes. Chemists are continuing to explore the role of ozone in the atmosphere. Another area that concerns several sectors of the research community is computer crime. In order to provide for better security, including the protection of communications lines from eavesdropping, computer scientists are exploring ways to implement simple, low-cost, but effective encoding techniques for use by the civilian sector.

Support of basic research is important and necessary; it provides a knowledge base for attacking problems that we may not even be aware of at the present time. The ultimate objective of all research is the complete

understanding of natural occurrences. The pure mathematician, for example, creates new mathematical knowledge which may eventually be used to increase our understanding of the physical, biological, and social worlds. Unlike other areas of science supported by NSF, research in pure mathematics derives essentially all its Federal support from the Foundation. A second example of the search for pure knowledge is in physics. During 1977 physicists working at the Fermi National Accelerator Laboratory, with NSF support, discovered a new particle, *upsilon*, believed to be the manifestation of a new kind of quark. This discovery implies the possible existence of previously unsuspected phenomena in the physical universe.

symmetry and conservation laws and the nature of the weak interaction.

Atomic, molecular, and plasma physics studies properties of atoms and molecules and higher levels of aggregation for which the atomic characteristics are represented in macroscopic behavior.

Theoretical physics promotes study of the theoretical framework within which experiments are interpreted. Emphasis is on understanding basic constituents of matter, the structure and interactions of nuclei, calculations of atomic and molecular properties, and other topics.

Gravitational physics studies the effects of gravitational phenomena from the astronomical to the microscopic domain. Examples are mathematical relativity, physical processes in strong gravitational fields, and the detection of gravitational radiation.

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## Physics

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Physics is that branch of science studying 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 other fields of science and has provided the underpinnings for many of our current advances in science and technology.

NSF's physics program supports experimental and theoretical research in elementary particle physics (sometimes referred to as high energy physics); nuclear science (which encompasses intermediate energy physics and nuclear physics); atomic, molecular, and plasma physics; and gravitational physics.

Elementary particle physics involves the search for new subnuclear states of matter, their properties, and the quantitative character of the forces that operate in the interaction of these particles with one another. Experimentalists study the interactions of high energy particles impacting on targets in accelerators and in cosmic rays.

Intermediate energy physics explores nuclear structure with particle probes that reveal the positions and motions of neutrons and protons in nuclei, and studies effects due to the microscopic substructure of the neutrons and protons themselves.

Nuclear physics seeks to determine the characteristics of the strong force (the force that particles such as protons and neutrons exert on each other) and the quantitative relationship between this force and the properties and dynamics of nuclei. Further, it uses the nucleus as a laboratory to study universal

### Parity Violated or Parity Preserved?

The weak interaction is the force responsible for the instability of many atomic nuclei, which decay by emitting a high energy beta particle (electron or positron) accompanied by a neutrino. A typical beta decay is the basis of carbon dating, in which carbon-14 decays into nitrogen-14 with the emission of an electron and a neutrino. Alternatively, one can rearrange this reaction, scattering the neutrinos from carbon-14 and yielding an electron plus the nitrogen-14. In that case, the incoming neutrino is transformed upon scattering into an outgoing electron. This is designated as a "charged current" process and is presumed to occur as a result of the exchange of a (yet-to-be-discovered) very massive charged particle—the *W* boson—which mediates the weak force.

This was thought to be the whole picture until Steven Weinberg, now at Harvard University and supported by



an NSF grant, and Abdus Salam of Imperial College, London, proposed in the late 1960's a theory of the weak force that predicted the existence of a new type of interaction mediated by a heavy neutral particle—the  $Z^0$  boson—which would give rise to so-called "neutral current" events wherein an incident neutrino scatters weakly from a nuclear target while retaining its identity. Such processes were detected experimentally several years thereafter by groups working at CERN in Geneva, Switzerland, and at Fermilab in Illinois.

A variety of neutral current reactions involving neutrinos have by now been studied, and thus far the Weinberg-Salam theory is consistent with all experimental data and has become the standard framework on which much of weak interaction work, both theoretical and experimental, is based. However, this model also predicts a  $Z^0$  boson exchange between electrons and a central nucleus, which leads to the prediction of departure from mirror symmetry in atomic transitions.

Such a departure from mirror symmetry, referred to as parity violation, is predicted by the Weinberg-Salam theory. This theory unifies the ordinary electromagnetic force, which conserves parity, with the weak force, which is known to violate parity. The departure would be very tiny, however, since this weak force has much less strength than the dominant electrostatic attraction.

This possibility has been subjected to experimental study recently in an experiment carried out by E. Norval Fortson and his colleagues of the University of Washington, Seattle. To date, they see no departure from mirror symmetry, which puts the Washington experiment in disagreement with a key prediction of this otherwise successful theory of elementary particle forces.

The Washington experiment was unusual because, in an age of large accelerators, the group used only a

table-top sized apparatus to study interactions of elementary particles. They sent a beam of polarized laser light through atomic bismuth vapor and looked for a very small rotation of the plane of the polarized light. Such a rotation would reveal the presence of a force in the bismuth atoms that does not possess mirror symmetry and that induces a twisting action by the atoms on the light analogous to the turning motion of a screw. The angle of rotation in bismuth vapor, assuming the Weinberg-Salam theory, has been calculated to be very small: somewhat less than a tenth of a second of arc. That is equivalent to the angle subtended by a grain of table salt about a mile away. Despite the fact that the experimenters are able to detect optical rotations a tenth of this size, they do not see the rotation predicted.

The optical rotation experiments provide a decisive test of the Weinberg-Salam theory. To double check, therefore, the detailed structure of the bismuth atom is being checked by more thorough calculations. If the atomic values used by Fortson are confirmed to be even approximately right, and if current experiments in bismuth and other elements continue to show a null result, then the Weinberg-Salam theory, in spite of its great successes, cannot be completely accurate.

The effort to understand this finding has led theoretical physicists to suggest that the weak force is actually rather different from what has always been assumed. In particular, it has been proposed that this force does not violate parity (distinguish left from right) in the extreme way suggested by earlier experiments. Salam and J. Pati of the University of Maryland, as well as R. Mohapatra of the City University of New York, D. Sidhu of Brookhaven National Laboratory, and A. DeRújula, H. Georgi, and S. Glashow of Harvard, have all proposed models in which the "neutral current" processes are mediated by *two* weak bosons,  $Z^0$ ,  $Z_2^0$ , and *do not violate parity at all*. All of these

physicists, except Salam and Sidhu, are NSF supported. Their works lead us to suspect that we have so far only seen and studied the "tip of the iceberg" of weak forces. Further study will require a variety of experiments, ranging from measurements on atomic systems to experiments with very high energy accelerators yet to be built.

### Upsilon: A "Beauty" Quark

A recent discovery of a new heavy and short-lived subnuclear particle, dubbed the  $\text{upsilon}$ , is interpreted by theorists to be the first hint of the existence of another new quark, thus expanding the list to five. The discovery could be the most important in elementary particle physics since the 1974 discovery of the  $J/\psi$  particle.

The  $\text{upsilon}$  discovery was made by NSF-supported university user groups who gathered data at the Fermi National Accelerator Laboratory, which houses the world's highest energy particle accelerator. The new object was identified as a minuscule component of the nuclear debris resulting from bombarding targets of copper and tungsten with proton beams of 400 GeV energy (GeV is an acronym for Giga, or billion, electron Volts).

The discovery's publication in the August 1, 1977, issue of the *Physical Review Letters* outlined the evidence for this new particle, said to be about ten times as heavy as a proton or neutron. The experiment examined the secondary particles, remnants of the initial collisions, which are decay products of the parent particles whose lifetimes are too short for direct observation. The mass of these parent particles can be calculated from the experimental measurements, which showed that, among the 9,000 rare events that were analyzed, there was a strong tendency for calculated masses to cluster near 9.5 GeV (expressed in energy units).



**Fifth quark?** Leon Lederman and John Yoh of Columbia University are shown here at Fermi National Accelerator Laboratory amid electronics used in the discovery of the  $\psi$  particle. This particle may imply the existence of a new quark, expanding to five the family of what are theorized as the most basic bits of matter. (Photo by Fermi National Laboratory)

Physicists from NSF-supported research groups at Columbia University and the State University of New York at Stony Brook, together with scientists from the Department of Energy-supported accelerator site, collaborated on the experiment. In all, 16 physicists were involved, under the leadership of Leon Lederman of Columbia. This project was part of an ongoing series of experiments to uncover the basic nature of matter and the laws governing its behavior.

In their publication, the experimental physicists refrained from drawing conclusions about the significance of the new particle. However, in context

with developments in particle physics over the past few years, there is beginning to be a consensus in the scientific community identifying the discovery with the existence of a new quark.

For a number of years physicists have suspected that protons and neutrons are composed of smaller pieces called quarks. All efforts so far to knock these proton or neutron quark-pieces apart and to observe them separately have failed. However, the fact that quarks do exist has been inferred with increasing confidence from a variety of experiments, and a theory involving three different kinds

of quark had initial success in describing the structure of elementary particles.

This three-quark picture had to be expanded to four quarks to accommodate the discovery of the 3.1-GeV mass  $J/\psi$  particle in 1974. That discovery won the Nobel Prize for Burton Richter and Samuel Ting. The quark inferred from that particle's existence is called the "Charm" quark.

In a similar fashion, the  $\psi$  discovery is believed to be a manifestation of a new quark. This fifth quark would have a new fundamental property, implying the possibility of previously unsuspected phenomena in the physical universe. The new quark has been called the "bottom" or, more whimsically, the "Beauty" quark.

### Direct Measurement for Carbon-14 Dating

Researchers at the University of Rochester Nuclear Structure Research Laboratory, in collaboration with groups from the University of Toronto and the General Ionex Corporation of Boston, Mass., have made a considerable improvement in carbon dating techniques. They have developed a new method of detecting very small quantities of carbon-14 with a sensitivity estimated to be two thousand to a million times better than conventional methods.

Carbon dating is a technique well known to archeologists and anthropologists for determining the age of ancient objects. Living organisms continually exchange carbon with the environment, which contains one carbon-14 atomic nucleus for every trillion carbon-12 nuclei. The dating method exploits the fact that when the organism dies, the proportion of carbon-14 decreases with time because this form of carbon is radioactive. It decays spontaneously, but quite slowly, by ejecting an electron to form nitrogen-14. In 5,730 years, about one-half of an initial quantity of carbon-14

will have decayed. Thus, measurement of the relative abundances of the carbon isotopes in any organic sample clocks its age.

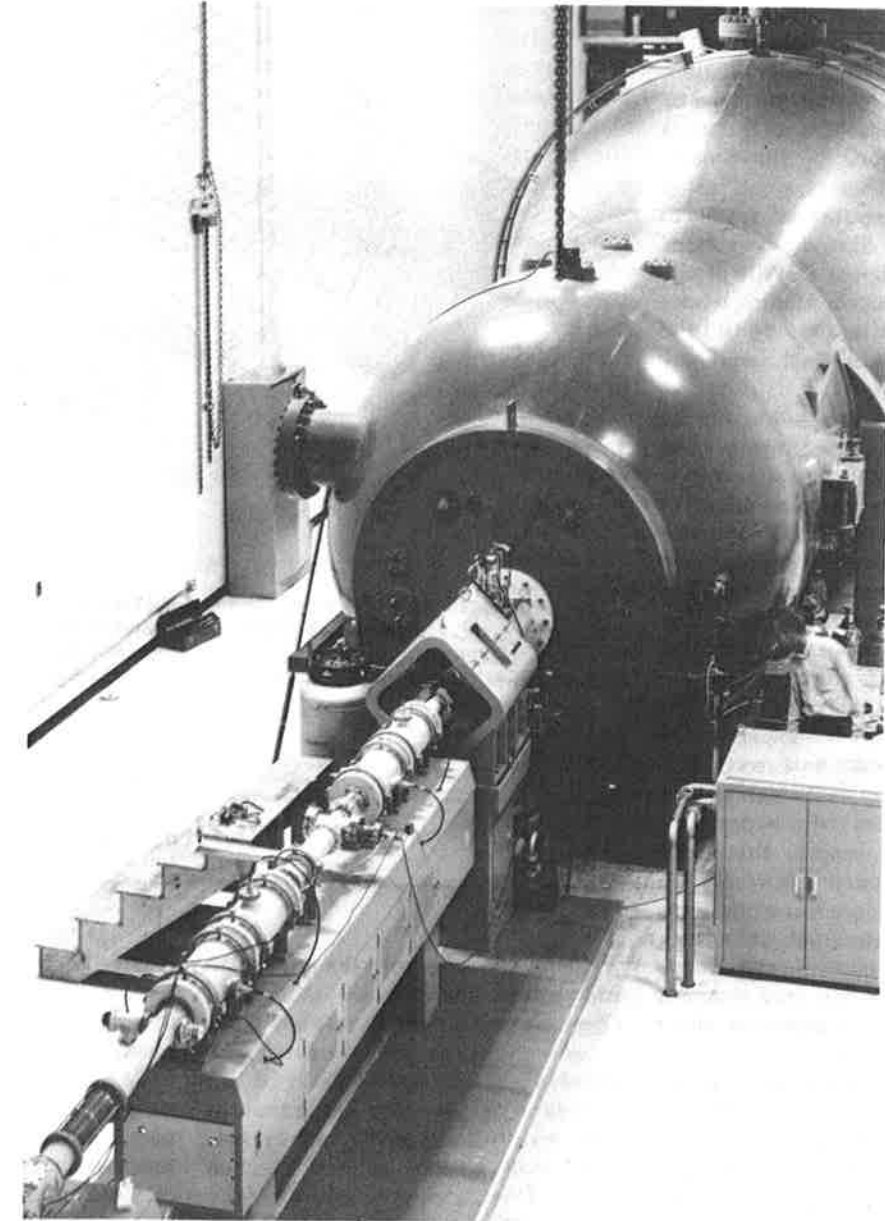
In conventional dating methods the radioactivity of the remaining carbon-14 is detected. The long half-life implies relatively little radioactivity, so large samples, on the order of 100 grams, of material are required. Harry Gove, director of the Rochester Laboratory, comments, "In the past, scientists have determined the age of objects by measuring the carbon-14 radioactivity. This is like waiting for a clock to tick in order to determine its existence."

In the new method, the carbon-14 nuclei are directly detected following acceleration through the Laboratory's tandem Van de Graaf accelerator, usually used to carry out research on the structure and interaction mechanisms of atomic nuclei. The key is *direct* detection.

A special source of negatively charged ions, originally developed for atomic nuclear research, requires a sample of only about 20 milligrams for the accelerator method. After acceleration, magnets effectively "filter" out all but the rare carbon-14 ions. The tandem accelerator principle, where the negative ions are stripped of their extra electrons during acceleration, is an essential ingredient of the new method, which results in greatly increased sensitivity compared to that of mass spectrographs used for atomic abundance measurements. The researchers are confident that ages up to 100,000 years can now be measured, in contrast to the previously existing limitation of about 30,000 years.

### "Seeing" Black Holes Collide (in a Computer)

A major breakthrough has occurred in classical general relativity during the past year. Larry Smarr of Harvard University, in collaboration with Kenneth Eppley of the University of



**Carbon dating.** Using this tandem Van de Graaf accelerator at the University of Rochester, scientists have developed a new, very sensitive method of detecting small amounts of carbon-14. Results of this work permit age-dating that requires extremely small samples of the ancient artifact and should triple the time span over which carbon dating can be used.

Maryland, has succeeded in computing the gravitational radiation produced by the head-on collision of two black holes. This is the first instance where a fully dynamic, nonlinear solution of

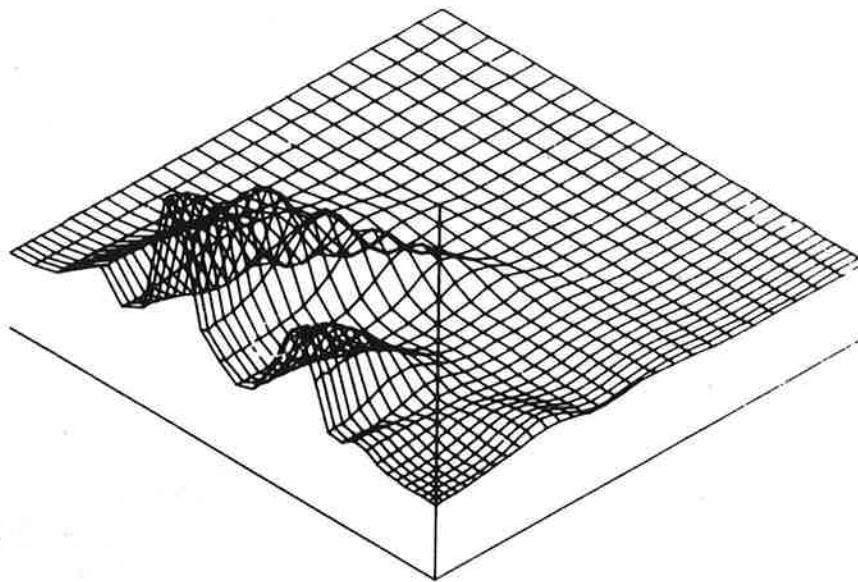
Einstein's equations has been obtained numerically.

Previously, many investigators have studied small perturbations of special solutions (such as Kerr black holes).

Unfortunately, such simplifications prevented the study of realistic models for sources of gravitational radiation, such as nonspherical stellar collapse or colliding black holes. This restriction is completely removed in the Smarr-Eppley work. The idea of using sophisticated computer programs to solve the full Einstein equations originated with Bryce DeWitt of the University of Texas, Austin, whose preliminary work in 1966-74 laid the groundwork for the final assault by Smarr and Eppley.

The successful completion of the program required developing new techniques in gravitational radiation theory as well as years of effort to perfect a stable, accurate computer code to solve Einstein's equations. However, now that these techniques have been "battle tested," they will be extended to study all of the heretofore unexplored but hypothesized sources of gravitational radiation that the current NSF-supported experimental program is working to detect. This new theoretical capability is thus quite timely and essential to the experimental effort. Furthermore, this work provides a "computer laboratory" in which one can explore many questions of principle in general relativity, such as the Cosmic Censorship Hypothesis ("Nature will hide any breakdown of the theory"), which underlies all of modern black hole theory.

A particularly valuable aspect of the Smarr-Eppley project has been the development of computer graphics to display the results of these complicated calculations. Using the Lawrence Livermore Laboratory computer system, Smarr and Eppley were able to make color films portraying the details of the collision and of the gravitational radiation produced in the collision. Besides being very instructive to nonexperts in relativity, it gives the same power for visualizing complicated solutions to partial differential equations that workers in plasma physics and hydrodynamics have come to depend on.



**Propagating wave.** As a result of a monumental advance in using a computer to solve classical general relativity equations, it should now be possible to compute gravitational radiation resulting from any hypothesized source. Computer graphics such as this provide powerful tools for visualizing the results of complex calculations.

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## Chemistry

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Chemistry deals with the properties and transformations of molecules. Chemists study molecules as simple as oxygen and as large and complex as proteins and DNA. The goals of the Foundation's research programs in chemistry include developing knowledge such that molecules can be designed from first principles and achieving understanding of and predicting chemical reactions important in nature and life processes.

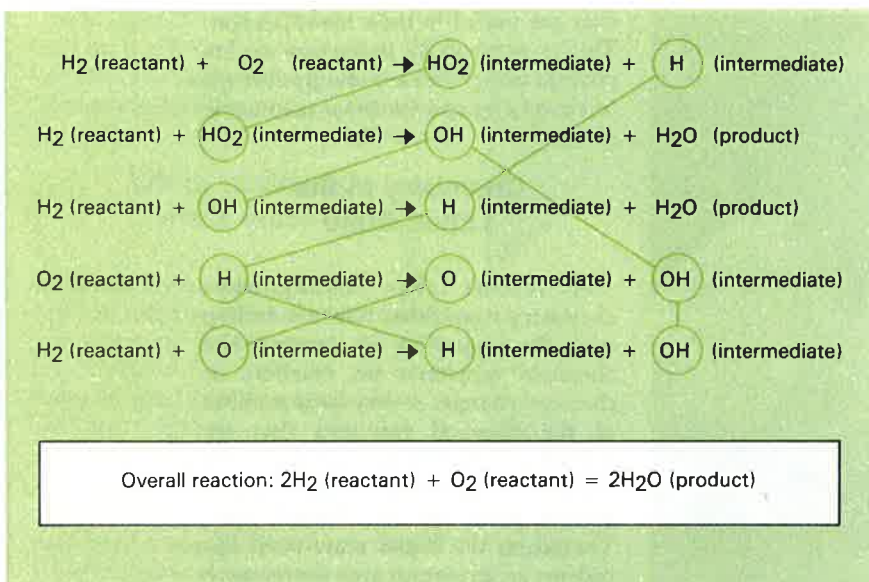
In striving to achieve these goals, chemists isolate, identify, and characterize naturally occurring molecules, synthesize new molecules, and develop theories that relate molecular structure and chemical properties. A large part of modern chemical research deals with chemical change. Chemists not only observe

change as it occurs in nature, but also seek to control and alter molecular interactions in order to serve human needs.

To understand a chemical reaction is no easy task. Even in cases where the overall reaction is simple, the chemical mechanism is frequently very complex (as the illustration on page 7 shows). To understand fully and control a chemical reaction, the chemist must understand each of the elementary steps involved in the conversion of reactant molecules to products.

Studies that uncover and explain such elementary steps form the core of modern chemical research. The principles derived from these studies guide chemical synthesis and are essential to interpretation in other sciences such as biology, geology, and astronomy.





**Intermediate reactions.** Although the chemical reaction in which hydrogen and oxygen combine to form water appears simple, the actual chemical mechanism is complex and there are several important elementary reactions also occurring. The sources of the intermediate chemical species are shown by the lines connecting species in different reactions.

Chemical research is proceeding at an accelerating pace, partly because chemists are now able to study chemical phenomena on shorter time scales (picoseconds, or trillionths of a second) and in smaller quantities (femtograms, or quadrillionths of a gram) than previously possible. This is due to the chemists' ingenuity in capitalizing on modern electronics, which has greatly improved the performance of such standard instruments as infrared and nuclear magnetic resonance spectrometers, mass spectrometers, and chromatographs. In addition, two powerful new tools, the microcomputer and the laser, have revolutionized the nature of modern chemical research. Computers have become an integral part of chemical instrumentation, vastly extending the research productivity and effectiveness of the individual chemist; the laser has opened up a multitude of opportunities for chemical research, including improved detection limits, accelerated reactions, improved spec-

troscopic resolution, more intense radiation sources, more efficient local heating, picosecond time scales, multiphoton dissociation and ionization, and new synthesis.

Despite many advances made by chemists and the importance of chemistry in medicine, industry, agriculture, and national defense, there are still important areas of chemistry where too little is known. The four project areas described on the following pages illustrate ways in which chemical research is pushing back the frontiers of ignorance in potentially important areas.

### Natural Products from the Sea

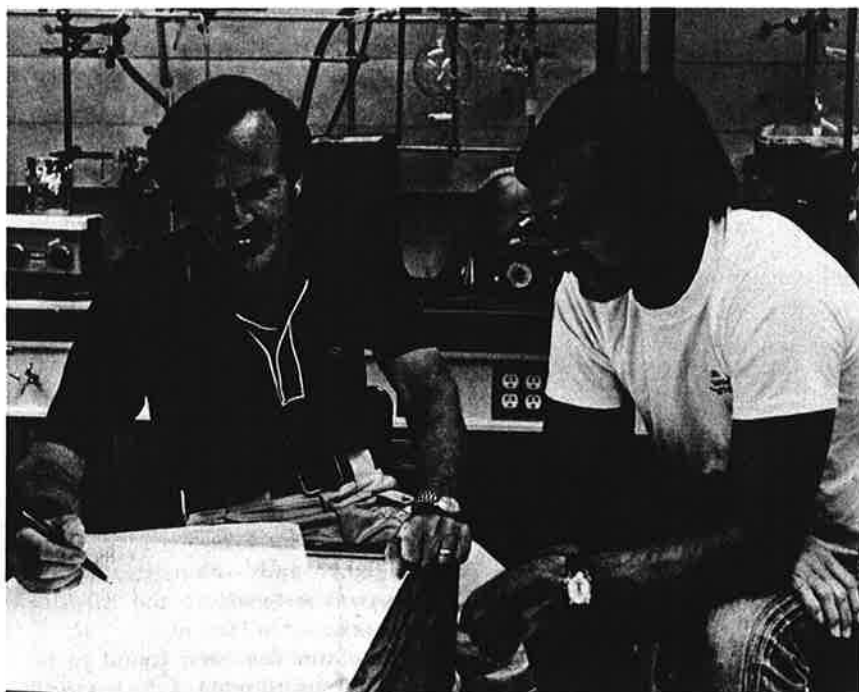
The fragrances of terrestrial plants have attracted the attention of man since antiquity. In fact, some of the earliest chemical investigations were conducted on the odoriferous constituents. Chemists now immediately associate the odors of trees and shrubs

with monoterpenes, of spices with phenols and their ethers, and of fruits and flowers with simple aliphatic esters. In contrast to this situation with terrestrial plants, fragrance in marine plants has been examined only to a limited extent.

Under the direction of Richard E. Moore of the chemistry department of the University of Hawaii, the odoriferous and toxic substances that are associated with some marine algae are under investigation. In a study of the odor of seaweed, the Hawaii researchers have found that two red seaweeds produce large amounts of volatile halogenated compounds. One of the seaweeds, known locally in Hawaii as *limu kohu*, "the supreme seaweed," and scientifically as *Asparagopsis taxiformis*, is the favorite edible seaweed in Hawaii.

Bromoform has been found to be one of the constituents of the seaweed and is responsible in part for the aroma and taste of *limu kohu*. This is particularly interesting since this volatile substance is suspected to be a human carcinogen, and there is concern about its presence in bromine-containing chlorine-treated drinking water. The analog, chloroform, has been shown to be carcinogenic in laboratory animals. The presence of bromoform and other suspected carcinogens such as carbon tetrabromide in *limu kohu* has recently prompted an epidemiological study of cancer in Hawaiians who eat seaweeds. The finding of bromoform and carbon tetrabromide in *limu kohu* is significant since it suggests that the natural chloroform and carbon tetrachloride in the upper atmosphere, which are believed to act as regulators of the ozone density, may have an algal origin.

Halogenated monoterpenes have been isolated from another red seaweed called *Chondrococcus hornemannii*. Most of these compounds are simple bromine- and chlorine-containing derivatives of myrcene. Myrcene, which is a constituent of oil of bay, can be readily converted into the



**Chemistry of ocean plants.** Richard E. Moore and Frank X. Woolard of the University of Hawaii inspect a nuclear magnetic resonance spectrum of a halogenated natural constituent of a Hawaiian seaweed. Such halogenated products are of interest as possible biodegradable insecticides. (Photo by Lars Bergknut)

halogenated compounds found in seaweeds. There is a growing interest in halogenated compounds from seaweeds as potential insecticides since natural pathways exist for the decomposition of these compounds.

In a study of toxic marine algae, the Hawaii group has investigated several species of marine blue-green algae belonging to the family Oscillatoriaceae. They have isolated a toxic substance from the lipophilic extracts of the blue-green algae *Lyngbya gracilis* and *Lyngbya majuscula* and identified it as debromoaplysiatoxin, a compound that had been isolated previously from the digestive gland of the gastropod mollusk *Stylocheilus longicauda* by Y. Kato in P. J. Scheuer's research group at the University of Hawaii. The Moore group has shown that debromoaplysiatoxin is the substance in *Lyngbya majuscula* that is responsible for a severe dermatitis

among swimmers who accidentally come into contact with this alga in Hawaiian waters.

Members of this same family of blue-green algae have been implicated as toxic in other types of human disorders, such as in gastrointestinal disorders from drinking water contaminated with toxic blooms of certain species of *Schizothrix* and *Oscillatoria*. There is an increasing incidence of water supplies becoming toxic in areas where drought has reduced water supplies and raised pollution levels while higher rates of eutrophication have increased the incidence of algal blooms in remaining water supplies. The Moore group has also isolated debromoaplysiatoxin from a mixture of *Schizothrix calcicola* and *Oscillatoria nigroviridis*.

The Hawaii researchers have found that the blue-green algae also contain specific types of nontoxic compounds

that are useful in their identification. This is particularly important as this phylum of algae is exceedingly difficult to classify by conventional taxonomic methods.

### Chemistry in the Liquid State

A feature that distinguishes chemistry from other sciences dealing with the properties of matter is the chemists' emphasis on reaction, or chemical change. A very large number of the chemical reactions that are carried out in the laboratory, in the industrial plant, or which take place in nature occur in the liquid state. Therefore, the liquid state itself has become an important area for research in chemistry.

Liquids are intermediate in nature between gases, which are almost completely chaotic in the ordering of their molecules, and solids, which are almost completely ordered. There is no simple picture of molecular order to use in understanding liquid properties.

Early attempts to understand liquids concentrated on the simplest possible case, that of liquids with spherical or almost spherical molecules. Insight into such systems has been contributed by computer simulations of liquids through techniques known as Monte-Carlo or molecular dynamics calculations. Measurements of the thermal properties of pure fluids and mixtures have also provided important insight.

An example of the insight one can get by computer simulation is the recent work of J. McTague at the University of California, Los Angeles. McTague has used the molecular dynamics method to study the crystallization of a fluid of spherical molecules with attractive forces. Solution of the equations of motion for the molecules was obtained by a computer.

Crystallization is initiated by the formation of a small nucleus, or germ, of the solid phase in the liquid. Since small nucleus formation is a rare event,

it is possible to supercool liquids. The computer results give the detailed time behavior of the formation of the new phase and show that a great deal of structural ordering occurs before the temperature and pressure have time to adjust to their values for the new phase. Experience gained with these systems is now being applied to systems of molecules with more complicated shapes. An example of a molecule of this latter kind is water, perhaps the most important solvent molecule of all.

Several spectroscopic techniques, such as nuclear magnetic resonance, X-ray and neutron scattering, and light scattering, have supplemented the classical techniques of thermal measurements and equation of state measurements to provide information about the local static and dynamic structure of liquids. Such experiments cover a wide range of pressure and temperature. One result of such studies is support for the idea that, at high densities, many of the properties of liquids are determined primarily by the repulsive forces between the molecules. The attractive forces, which hold the liquid together, play a relatively minor role in many aspects of liquid behavior.

Spectroscopic techniques have the advantage of probing local behavior of molecules in solution. Radiation absorbed by a single molecule provides a structure-sensitive probe since the wavelengths absorbed are affected by the surroundings of the absorbing molecule. An example of the kind of detailed information which can be gleaned from such experiments is the work of W. F. Edgell of Purdue University on the infrared spectrum of the ion cobalt tetracarbonyl in six different solvents. Edgell found that the ion existed in these solutions in at least five different environments, the structures of which can be inferred partially from the spectrum.

When a particular chemical reaction involving this ion was studied spectroscopically, it was found that only



**Molecules in solution.** Walter Edgell and his students at Purdue University examine spectrographic data bearing on the structures of ions in liquids. Such studies help chemists to understand the details of chemical reactions and may lead to improvements in chemical processes. (Photo by Purdue University)

three of the five structural types took part in the reaction; two were unreactive. These results, combined with the structural knowledge of the environments in solution, furnish important new insight into the detailed mechanism of this reaction on the molecular level.

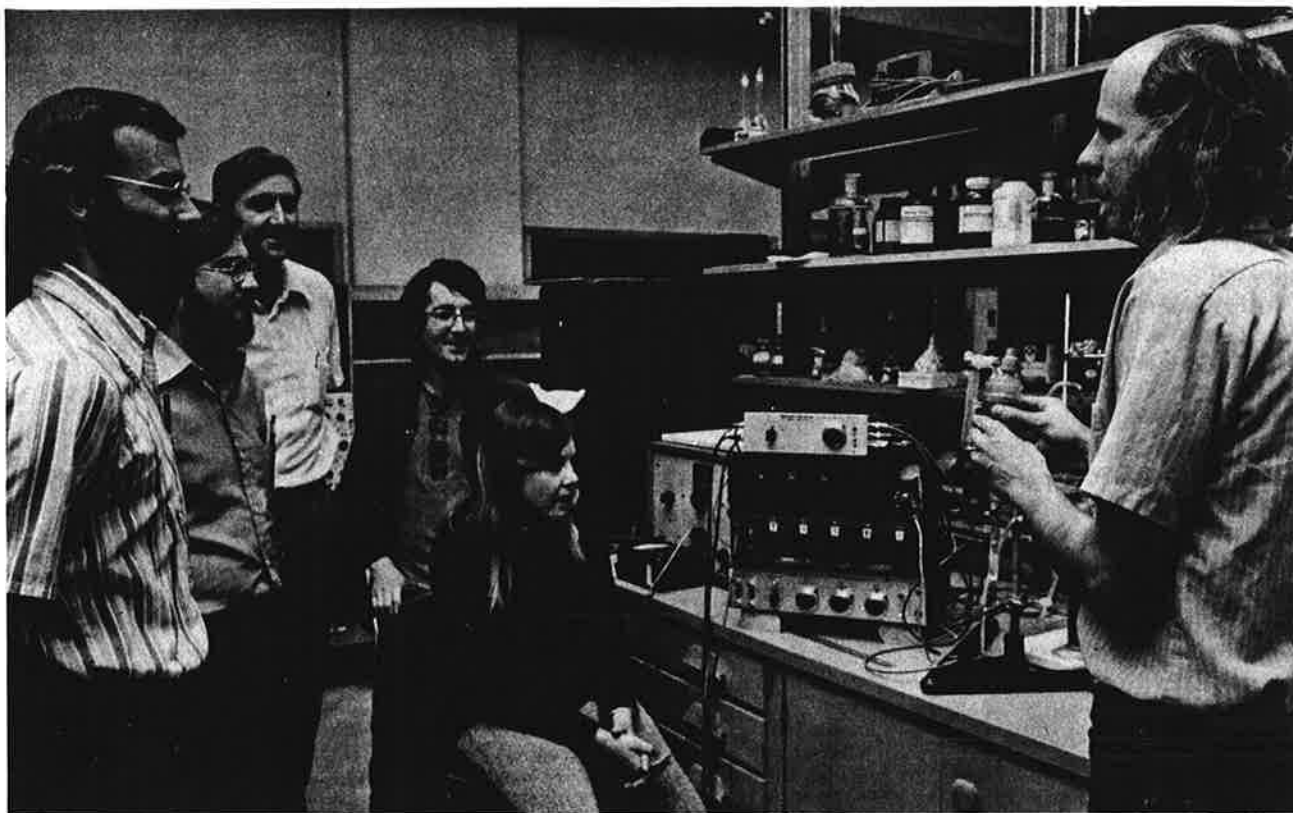
Studies such as this one can be expected to build up our armory of knowledge about how molecules react in solution to the extent that the best solvent medium for a particular desired reaction can be chosen on a rational and quantitative basis.

### Chemically Modified Surfaces

Electrochemistry has great potential for coping with the problem of increasing demands on a dwindling supply of conventional fuels. The

harvesting of solar energy by converting it directly into electricity, the storage of solar energy by the photoelectrochemical generation of hydrogen, the electrochemical "burning" of fuels derived from oil, and more efficient use of electricity in the highly energy-intensive chemical process industry are only a few examples of the potential of modern electrochemistry.

The key to success is the chemical preparation of electrode surfaces so that the desired electrochemical transformations proceed cleanly and rapidly. Frequently, a catalyst is required to achieve the rates necessary for efficient and practical operation. In such cases the electrode material itself can sometimes serve as an effective catalyst. Platinum electrodes, for example, are the best known cathodes for the rapid reduction of oxygen. However, platinum and other catalytically active precious metals are prohibitively



**Surface chemistry.** Fred Anson (rear) and his research group at Caltech are working on ways of producing electrodes with catalytic properties, an area of great promise for improving the efficiencies of economically important chemical reactions.

expensive for many applications. For this reason much effort has been devoted to finding chemical means for attaching one or two molecular layers of potent catalysts to the surface of inexpensive electrode materials.

Fred C. Anson and his coworkers at the California Institute of Technology have been studying the surface chemistry that controls the attachment of molecules to electrode surfaces. Their research has resulted in the identification of a number of general chemical reactions that can be exploited to attach catalysts to electrode surfaces. Transition metals such as rhodium and ruthenium, known to be highly effective catalysts in homogeneous solution, have now been attached successfully to electrode surfaces by Anson's group.

The rates at which the attached reactants are able to accept or deliver electrons determine their ability to function as catalysts in the attached state. Measurements currently in progress in Anson's laboratory have shown that extremely high rates of electron transfer can be achieved with a number of attached reactants. In fact, evidence is accumulating that merely attaching a molecule to an electrode surface will generally lead to a significant increase in the rate at which the electrode can operate electrochemically.

In one case it was shown that an attached molecule containing iron and a complex organic ligand significantly enhanced the rate of the electrochemical conversion of oxygen to water. The result is noteworthy

because the sluggishness of this reaction is the major obstacle impeding the development of efficient, economic fuel cells.

### Understanding the Chemistry of Ozone

The public controversy surrounding the purported deleterious effects of SST aircraft and fluorocarbon aerosol propellants on the stratospheric ozone layer has alerted the scientific community to the importance of thoroughly understanding atmospheric dynamics in general and the central role of ozone in particular. Ozone's environmental impact is enormously complex. Stratospheric ozone has a beneficial screening effect, which protects the Earth from short-

wavelength, high-energy solar radiation. Tropospheric ozone, on the other hand, has a damaging effect as an oxidant of plants, animal life, and manufactured materials.

Legislation designed to control oxidant levels focuses mainly on the concentrations of nitrogen oxides and hydrocarbons. This control strategy is based on considerable evidence that natural ozone levels can be altered in a complicated series of chemical reactions involving the nitrogen oxides, hydrocarbons, and sunlight. Unfortunately, the present incomplete knowledge of the variables in the atmospheric potpourri of chemistry makes it difficult to state with confidence what the optimal levels of ozone and other airborne chemicals might be. Nevertheless, from a variety of perspectives, and using different methodologies, numerous recent studies are converging to resolve some of the unanswered questions about ozone chemistry. Two cases in point may be cited.

The nitrate radical,  $\text{NO}_3$ , has only recently been recognized as a potential threat to ozone stability in the atmosphere. Nitrate is formed in a number of atmospheric reactions. It is a product of the reaction of nitrogen dioxide with ozone, and it is also formed by reaction with nitric acid vapor and as a thermal decomposition product from dinitrogen pentoxide. The nitrate radical absorbs visible sunlight strongly, causing its own destruction in many cases. The products are either (a) nitric oxide and molecular oxygen, (b) nitrogen dioxide and atomic oxygen, or both. If fragmentation mechanism (a) predominates, the result is a catalytic cycle that destroys atmospheric ozone. On the other hand, decomposition mechanism (b) leads to a series of reactions that are neutral with respect to ozone.

Research on the chemistry of the nitrate radical has been frustrated in the past by its low concentration levels and reactive nature. Despite these

difficulties, Harold Johnston and Richard Graham of the University of California, Berkeley, have succeeded in determining the products of photolysis of the  $\text{NO}_3$  radical. Although the results depend on the wavelength of the light, under atmospheric conditions only about one-third of the nitrate radical decomposition passes through the ozone-destructive catalytic cycle. Thus, it has been established that the  $\text{NO}_3$  molecule has only a marginal effect on atmospheric ozone concentrations.

Another aspect of ozone chemistry is being pursued by Robert Murray and his research group at the University of Missouri, St. Louis. This group is analyzing the reactions between ozone and hydrocarbon air pollutants. As part of this research, they have developed methods for producing suspected intermediates in ozonolysis reactions under controlled conditions. For instance, Murray has been able to generate the important class of ozonolysis intermediates, carbonyl oxides, by reaction of singlet (excited-state) molecular oxygen with diazo compounds.

This technique for generating carbonyl oxides has facilitated a

systematic study of the reactions of this intermediate with atmospheric pollutants such as aromatic hydrocarbons. A potentially important result derived from this work is the discovery of a synergistic interaction between ozone, olefins, and aromatic hydrocarbons. Both ozone and certain polycyclic aromatic hydrocarbons have been individually recognized as dangerous air pollutants. In the case of the polycyclic aromatic hydrocarbons it is thought that these "precarcinogens" are converted to "ultimate carcinogens" by enzymatic oxidation in the body. Murray's work suggests that there may be additional chemical paths to the "ultimate carcinogens," namely the reaction of ozonolysis intermediates such as carbonyl oxides with polyaromatic hydrocarbons. Thus, the combination of olefins, ozone, and polycyclic aromatics in polluted atmospheres could be the source of potent carcinogens.

The aim—to completely unravel the chemical impact of ozone on the environment—still seems far from realized, but these and other ingenious approaches are bringing chemists much closer to a full understanding of ozone chemistry.

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## Mathematical Sciences

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The objectives of the Foundation's research programs in the mathematical sciences are to create new mathematical knowledge and, through the application of mathematical knowledge, to increase understanding of phenomena within our physical and social environments.

The first of these objectives is achieved by the creation of new mathematical structures and techniques and by the analysis and study of relations that exist between them. The second objective is achieved by translating phenomena of the physical,

engineering, biological, environmental, and social sciences into mathematical problems and, by the application of existing or the creation of new mathematics, finding solutions to the mathematical problems so formulated.

Mathematics created with a motivation that lies within mathematical theory itself is called core mathematics. Mathematics consciously created or used as a tool for understanding various aspects of nature or society is called applied mathematics. Both motivations are pervasive in the mathematical world which, thereby, both



gives and gleans benefit: Mathematics serves as a language and tool for the other sciences, while the problems presented by the other sciences stimulate the creation of new mathematical ideas and techniques. Such interaction, both among subareas of mathematics and between mathematics and other disciplines, has been a key ingredient of progress in the mathematical sciences during the past quarter century. Both types of interaction are evident, for example, in the relationship between algebra and geometry, started in earlier times, and the more recent incorporation of some of the results of that phenomenon into physical theory. This same past quarter century has also been one of the richest in history in terms of the production of solutions to important, longstanding mathematical problems. Both trends continue; some of the areas in which major activity is under way along each of these mathematical "tracks" are discussed on the following pages.

### Recent Advances in Celestial Mechanics

Several recent advances have been made in the study of the singularities of the classical  $n$ -body problem in Newtonian mechanics, where the gravitational bodies are treated as point masses. A singularity is defined as a point where the equations of motion cease to be valid. There are, in principle, two possible types of singularities: a collision, or a "near-miss singularity" in which some bodies come closer and closer together in finite time but never collide.

The classical study of these singularities has two important results. Around 1895, P. Painlevé showed that the near-miss singularity cannot exist in the  $n$ -body problem when  $n$  is equal to or less than 3. The question of whether these singularities exist for the  $n$ -body problem when  $n$  is equal to or greater

than 4 has remained open. Later (in 1913), the late K. Sundman showed that the equations of motion for the  $n$ -body problem can be continued through a double collision. Physically speaking, this continuation is tantamount to treating the double collision as an elastic bounce.

Within the last few years D. G. Saari of Northwestern University has shown that the set of initial conditions that gives rise to collision singularities for the  $n$ -body problem is a negligible set, or a small set, in a measure-theoretic or topological sense. In another direction R. McGehee of the University of Minnesota has developed a new approach to the study of the set of initial conditions that gives rise to collisions. Specifically, in the planar 3-body problem, McGehee has studied the flow in the vicinity of a triple collision. He has shown that the point of triple collision can be replaced with a suitable manifold and that the flow near a triple collision extends to this manifold. In this way, by studying the flow on this manifold, one can get a qualitative picture of the behavior of trajectories in the vicinity of a triple collision. This point of view seems to be very promising for future developments in celestial mechanics.

By using this theory, McGehee and J. N. Mather of Princeton University recently constructed a near-miss singularity for the Sundman variation of the Newtonian 4-body problem. It now seems plausible to expect that the original 4-body problem may have near-miss singularities.

### Superalgebras

A new idea has appeared in the world of physics. It is called "supersymmetry." When it was first proposed by the Russian physicist Stavraki in 1966, it attracted no attention. The idea was rediscovered around 1973, however, and a substantial number of theoretical physicists have been actively studying it since then. In turn, mathematicians have

been looking at its purely mathematical aspects. In this form it is referred to as the theory of "superalgebras."

Any natural situation in mathematics or physics is likely to be accompanied by a measure of symmetry. For a modest example from mathematics, think of an equilateral triangle: There is no real distinction to be made among the three vertices; they can be moved around in six ways, which form the "symmetry group" of the triangle. The symmetry groups that arise in physics are likely to be just such nice geometrical objects. About a decade ago, for example, the Lie group, denoted  $SU(2)$ , in which special unitary matrices act on a space having *two* dimensions, was found to have considerable importance in physics.

The structure of Lie groups was pretty well determined nearly a century ago, when the "simple" ones—the ultimate building blocks—were classified. First there were those that arise in a natural way in geometry and which held no surprises for mathematicians. In addition, however, there were five that were surprising: five "exceptional" or anomalous groups that act on spaces the dimensions of which are 14, 52, 78, 133, and 248. These dimensions are often called the "magic numbers" of Lie group theory.

In an ordinary Lie group, a differential calculus can be introduced in the manipulation of the group. This transmutes what used to be called an "infinitesimal" Lie group into what is now called by the better name: "Lie algebra." In a Lie algebra the basic mathematical operation behaves like the "commutator"  $xy - yx$ . In ordinary algebraic situations this expression would, of course, be zero; in these more general and abstract situations, however, there can be other consequences.

Where supersymmetry occurs there are two kinds of objects, called Bose and Fermi by physicists and called odd and even by mathematicians. Two of these objects will combine mathematically in commutator fashion *except*

when both are odd. In that case, the combination behaves like an "anticommutator"  $xy$  and  $yx$ , and a different mathematical object has arisen. It is called a "Lie superalgebra." It is here that the notion of "supersymmetry" arises.

Once again, the main action takes place in the search for building blocks: the simple Lie superalgebras of which the more complex ones are comprised. There is a list of those with which mathematicians are familiar. But once again there are surprises.

Beginning in 1974 a number of mathematicians, at first working independently and then in various combinations, began to attack the problem of building the exhaustive list of Lie superalgebras and the dimensions of the spaces in which these objects operate. In the group were Z. Djokovic of the University of Waterloo in Canada; Gerhard Hochschild of the University of California, Berkeley; Irving Kaplansky of the University of Chicago; Shlomo Sternberg of Harvard University; and Victor Kac of Moscow University and now at the Massachusetts Institute of Technology.

Completion of the list was due to Kac, who found that there are, indeed, surprises, just as there were "magic numbers" in ordinary Lie theory. For the Lie superalgebras, the exceptions are cases in which there are 17, 31, and 40 dimensions. A surprise within a surprise, however, is that in the 17-dimensional case there is an infinite variety of exceptional Lie superalgebras.

In almost all of the cases in which work was done on the study of Lie superalgebras, it turns out, strong groups of algebraists were working in close proximity to strong groups of theoretical physicists.

The speed—3 years—in which this major project was completed is remarkable. Now, say the mathematicians, the ball is back in the physicists' court, and ways of applying the mathematics are being studied.

### Resolution of the Smale Conjecture

The smooth, reversible deformations of a sphere onto itself include all the rigid ones (rotations and reflections) plus a great many more. Nevertheless, there is a significant underlying resemblance between these two collections of transformations: (1) each collection may be considered as a geometric object, two transformations being considered close to each other if they have nearly the same effect upon each point of the sphere; (2) the fundamental connectivity of these two geometric objects is the same, one being simply a thicker version of the other, much as an annulus is a thicker version of a circle. The technical term for this is homotopy equivalence, and its symbol is  $\cong$ .

If one calls the collection of smooth deformations  $S^2$  and the collection of rigid motions  $R^2$ , then one can put the homotopy equivalence relationship succinctly:  $S^2 \cong R^2$ .

One may consider the analogous question for the circle, and the same answer obtains and an analogous notation,  $S^1 \cong R^1$ , applies. Correspondingly, one can generalize to higher dimensional analogs of spheres.

In 1960, Stephen Smale, now at the University of California, Berkeley, proved  $S^3 \cong R^3$ . He conjectured  $S^4 \cong R^4$ , but, despite the best efforts of a regiment of very able mathematicians, the proof of that homotopy equivalence eluded everyone until last year. Then Allen Hatcher, now of the University of California, Los Angeles, succeeded, using a long and elaborate series of constructions of his own devising. Both the result and the methods he used to prove it promise to have other important consequences. (It has been known for some years that the analogous result for  $S^6$  and  $R^6$  is false, the existence of the so-called exotic spheres of John W. Milnor of the Institute for Advanced Study and Michel Kervaire at the University of

Geneva being one obstruction, so only the case of  $S^5$  and  $R^5$  remains unsettled.)

### Bifurcation Theory and the Origin of Life

One of the central questions of the origin of life is: How did the structures such as proteins, nucleic acids, and cells arise from an inert, prebiotic mixture of simple molecules? A. M. Turing in 1952 suggested that a system of chemical substances, called morphogens, originally homogeneous, may develop a pattern of structure due to an instability of equilibrium triggered by random disturbances.

This idea has been pursued by scientists who proposed simplified mathematical models to illustrate the concept. But no one showed that the instabilities basically were branching of the solutions (bifurcations) as a parameter (e.g., concentration gradient) changed. Secondary bifurcation may also occur, and this means that after a bifurcation one of the branches bifurcates again. Bifurcation, therefore, can describe the existence of a physical system in several states simultaneously.

Supported by an NSF grant, T. J. Mahar, now at Utah State University, and B. J. Matkowsky, now at Northwestern University, while they both were at Rensselaer Polytechnic Institute, demonstrated that in a modeled biochemical reaction, secondary bifurcation does, in fact, occur so that the system may evolve to states with spatial structure. They used an important mathematical method developed by L. Bauer and E. L. Reiss of New York University's Courant Institute (both NSF grantees), and H. B. Keller of the California Institute of Technology. The calculations show a hierarchy of solutions to the steady state problem, each level displaying more structure than the previous one. The model is, as Turing observed, "a simplification and an idealization, and consequently, a falsification" of actual,

physical life-spawning systems. But the model has important features that will be helpful for further investiga-

tion, and the results are a forward step in approaching the mystery of life's origin.

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## Computer Science

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

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

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

Computer science sprang from a remarkable fusion of abstract logic and electronics accomplished by mathematicians, logicians, philosophers, and engineers. It has been force-fed by strong commercial demands for service and a revolution in electronics technology that continues to this day. So strong has been the demand for the products and applications of computers, in fact, that they nearly swamped the field; it has been a

struggle for the discipline to reassert its scientific origins.

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

### An Application of Complexity Theory

Much theoretical work in the past decade has focused on the concept of computational complexity; i.e., the inherent difficulty of performing different kinds of computational tasks. It is now becoming clear that complexity theory is one cornerstone of computer science; it has applications in every area of study.

A recent application of interest concerns computers and communications. Over the next few years, revolutionary developments in computers and communications will drastically alter the way in which we process and exchange information. Electronic funds transfer systems, electronic mail, and distributed corporate computer networks are only a few important examples of computer communications in the future. As these applications develop, so will the need to secure the transmission, motivated by concerns for personal privacy, corporate secrecy, and data security.

While securing a computer system is a complex and multifaceted task, one important part of it is to protect the communication line from eavesdropping or from tampering (by introducing false messages or altering the real message). Encoding the digital communications is the apparent strategy. NSF grantees, as part of their research on the securing of computer systems, have been seeking ways to implement simple, low-cost, but effective encoding in civilian-sector applications.

Traditional techniques are either very secure but expensive and cumbersome, or are not demonstratively secure except by tests of their resistance to attack by code-cracking teams. Martin Hellman and Whitfield Diffie at Stanford University, drawing on recent advances in complexity theory, have developed a set of encoding schemes that have two advantages:

- Since the encoding rules are different from the decoding rules, the decoding scheme need never be sent from the receiver to the message sender. Indeed, since its parameters are generated in the receiver's computer, it need never be known by anybody.
- Even were the relationship between the published encoding



and secret decoding rules known, it would be a measurably difficult task to derive the decoding key for any specific message.

Hellman and Diffie were able to demonstrate several classes of functions that provide such cryptographic codes. (After learning of the work of Hellman and Diffie, R. L. Rivest, Adi Shamir, and Leonard Adleman of the Massachusetts Institute of Technology discovered a particularly effective class of functions for this purpose, while doing research on the computational complexity of certain highly abstract areas of number theory.)

These new encoding and decoding schemes allow not only secure communication, but also such additional benefits as the ability of any user electronically to "sign" or validate messages uniquely. Thus, every person may be able to be provided with a unique electronic "signature" that cannot be forged but can be recognized by every receiver of that person's message.

### Stability of Computer Models

In order that computational results be trusted with respect to analysis or forecasting of events, it is necessary that the computing process be stable. By "stable" we mean that a small change in the data being used in the model shall induce a similarly small change in the computational behavior of the model. A model and its computing process are considered to be unstable if a slight change in the data can cause an unacceptably large change in the computational results from the model. If a model is stable we consider it to be well conditioned and well posed.

Frequently, the process of model building in the social sciences is a mixture of art, science, and intuition. As the power of computing machines

increases, the size of the models continues to grow. As the size of a model grows, the probability is increased that variables within the model interact and relate to each other in such a way as to cause unstable computational behavior. One can now counteract this situation constructively by isolating dependent and independent variables in a linear model; for the first time the separation of variables has been put on a firm theoretical and computational foundation and can be done with reliable, semiportable software.

Gene Golub of Stanford University, Virginia Klema of the National Bureau of Economic Research, and G. W. Stewart of the University of Maryland have brought the powerful mathematical tools of numerical algebra (matrix analysis, in particular) to bear on the problem. (The numerical work is

described in "Rank Degeneracy and Least Squares Problems" by Golub, Klema, and Stewart and has appeared as a technical report at Stanford, the University of Maryland, and the National Bureau of Economic Research.)

The three have also produced reliable and stable software for the use of scientists in diverse disciplines who are constructing computer models for the study of complex phenomena. One of the projects using this software was a study by David Harrison of Harvard University and Daniel Rubinfeld of the University of Michigan, using the price of housing as a measure of the willingness of people to pay for improved air quality. Another researcher using this software is Alan Miller of the Australian National University, who is analyzing the effect of cloud seeding on rainfall.

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## Engineering

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The profession of engineering is concerned with providing solutions to society's technological problems. As a profession, it can continue to do this only if there is a continual flow of new members into that profession and if the knowledge base the profession uses is expanding so it can meet the new challenges presented to it. The National Science Foundation's engineering program supports basic engineering research to increase the understanding of fundamental engineering principles and in so doing increase our ability to manage and use our physical resources.

These engineering research projects address problems that lead to new design principles or represent completely new approaches to important problems. As distinct from other Federal agency programs, where the research supported is directed at

providing solutions to problems addressed by that agency, NSF's engineering program has the basic mission of supporting the well-being of engineering research in general; it complements research supported by the mission agencies. NSF-supported basic research is concentrated in universities and performed by faculty members and graduate students. Thus, as they provide new knowledge through their research activities, the faculty members are able to pass new knowledge on to their students, ensuring that both the universities and the students produced by them are of high quality. It is the students who continually replenish the personnel of the engineering profession; this replenishment is essential to its continued vitality.

Not having specific engineering problems to solve, but rather being

concerned with basic engineering principles, NSF can support what would be regarded as high-risk activities. If, in fact, the risk pays off, then the follow-on work taking it to the point of application would be appropriate for a Federal mission agency or industry.

In order to respond appropriately to a variety of problems in engineering, NSF's engineering program is organized into 13 areas grouped under the general headings of electrical sciences and analysis, engineering chemistry and energetics, and engineering mechanics. Through close liaison between these program areas and other programs of the Foundation whose activities impinge upon engineering, NSF is able to respond to virtually any research proposal addressing a basic engineering issue.

Research in electrical sciences and analysis continues to focus on electronic and other devices and systems that assist in providing for energy and informational needs. An important step in this area was taken in 1977 with the establishment of the National Research and Resource Facility for Submicron Structures, in cooperation with Cornell University. Through this facility, researchers throughout the Nation will be able to pursue research on ultraminiature electronic, magnetic, optical, acoustic, and superconducting devices. This program also supports theoretical and experimental research on the elements of automated decision and control in physical and biological systems. It is hoped that the advances made will lead to the realization of opportunities in advanced automation and robotics, which can lead to increased industrial efficiency, and in the general areas of image processing and biomedical engineering. At the same time, research is continuing on control systems, especially as applied to large-scale dynamic systems such as those for energy, transportation, and water.

Research in engineering chemistry and energetics has led to the delineation

of fundamental kinetic mechanisms in heterogeneous catalysis and improved understanding of the nature of the adsorbed species in such energy-producing processes as coal gasification and methanation. Theoretical work in thermal radiation has resulted in predictions about the spectral absorption and total absorption properties of radiating gases. Coupled with experimental advances being made in shock tube technology, more efficient and environmentally compatible combustion processes are being developed. As a result of development of technology for precision fabrication of membranes, various transport models relevant to the processing of chemicals, food, and waste products can now be tested. Research on the basic mechanisms of pulverizing mineral ores has led to computer control of the entire process with higher energy and material efficiencies to hold down the costs of coal and other products that must be ground.

In engineering mechanics, significant progress has been made in a large number of areas. New knowledge about the physical-chemical, thermal, and microstructural behavior of clay-soil and cement paste, as well as of the probabilistic approach and optimization techniques in structural engineering, can help engineers design more economical structures. In fluid mechanics, fundamental studies dealing with low-density, high-speed gas dynamics are proceeding, as well as studies on turbulent shear flow. Further studies on the inelastic behavior of materials and on material evaluation through nondestructive means are being undertaken. Fundamental study of the transport of sediment, heat, and other pollutants in water should lead to better understanding of how to manage water resources, and research on the interactive mechanisms of wind and waves and the effect of wind on structures is particularly important in the design of coastal and offshore structures.

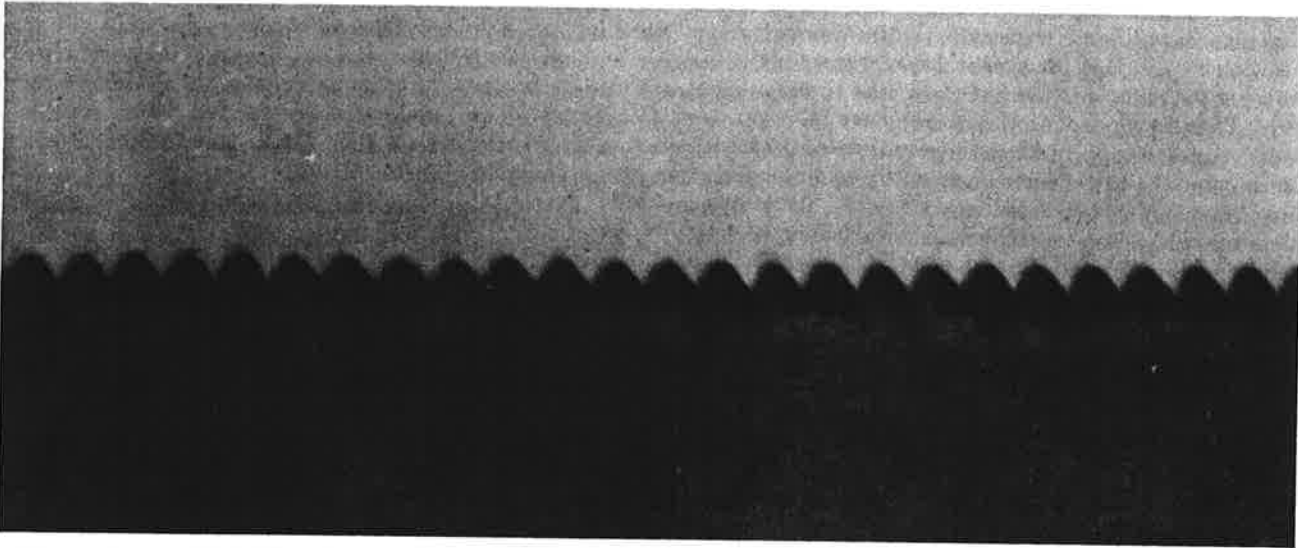
## The National Research and Resource Facility for Submicron Structures

The National Research and Resource Facility for Submicron Structures is the first attempt by NSF to provide a national facility to encourage and expedite engineering research. The decision to establish the facility followed several years of discussion with the research community that resulted in a consensus view that the facility would offer a greater likelihood of producing significant research than would investing a similar sum in individual grants. The grant provides \$2,000,000 for the first year and \$750,000 per year for the following 4 years. Over \$2,000,000 of the total is budgeted for the initial acquisition costs of the equipment needed for submicron research. Additionally, Cornell University is making a substantial contribution to the purchase of equipment. The equipment at the facility will be made available to interested researchers from all over the country.

In this role as a prototype for cooperative engineering research, the facility is being closely observed not only by the National Science Board and the administration of NSF but also by interested members of the research community and related industrial organizations.

The research of this center will involve a broad attack on problems of electron-beam and X-ray lithography, which are required to achieve geometries in the submicron domain. The main emphasis will be on the ultimate limitations of these techniques in achieving geometrical patterns of small dimensions. Real advances will come when breakthroughs are achieved in such areas as electron-beam sources, electron optics, platform stability, and scattering properties of electrons in materials.

This will be a facility where research



**Ultrasmall.** The new National Research and Resource Facility for Submicron Structures will permit advanced research in the use of electron beams and X-rays to produce microscopic structures, devices, and systems, such as this holographic grating on a gallium arsenide base (with a grating period of 0.33 micron). This research will allow exploring the little-known region between systems of atomic dimension and the very important existing systems using microelectronic devices.

workers with different types of science or engineering backgrounds and from many different institutions can participate in the design and fabrication of experimental structures, devices, and systems needed in research involving submicron dimensions. The techniques of microfabrication may also be of use in generating what can be called artificial molecules of unusual interest and importance. The possibility of fabricating extremely small electronic systems suggests unusual opportunities for building biological probes to be inserted in single cells.

The facility will be housed in a new wing being added by Cornell to Phillips Hall, the location of the department of electrical engineering. Joseph M. Ballantyne, professor of electrical engineering, coordinated the activities of an interdisciplinary faculty group from the departments of electrical engineering, applied physics, and chemistry in planning the facility. Its organization follows a plan common to such centers: A policy committee will establish overall policy, and a program committee will oversee day-to-day

operations and select projects from proposals submitted by prospective users. The professional staff will be headed by a director who is yet to be named. (Ballantyne is serving as acting director.) When the facility is in regular operation the members of the program committee will be selected by the users group, with a majority of the committee from outside Cornell. For the start-up period an *ad hoc* program committee has been appointed whose outside members are R. F. W. Pease of Bell Telephone Laboratories; E. D. Wolfe of Hughes Research Laboratories; A. N. Broers of Thomas J. Watson Research Center, IBM; William S. C. Chang of Washington University, St. Louis; and H. T. Henderson of the University of Cincinnati.

### Structure of a Turbulent Spot

Flow in a fluid often changes from a laminar or well ordered flow to a turbulent one in which there is significant randomness. The transition to

turbulence, which enhances mixing and is often desirable (in heat flow or pollution transporting situations, for instance), has remained a frontier in fluid mechanics research; measuring and quantifying the characteristics of even isolated "spots" of turbulence as a fluid begins to change from one kind of flow to the other has, until now, been beyond the capability of available instrumentation. As a consequence, though there is considerable interest in the physical phenomenon of turbulence, most mathematical models of fluid flow continue to deal with the more orderly laminar variety. Inducing or controlling turbulence, therefore, has remained a hit-or-miss matter, in spite of extensive work during the past two decades.

It was discovered in the early fifties by Howard Emmons at Harvard University and later confirmed by researchers at the National Bureau of Standards that the appearance of turbulent spots in a laminar region close to a wall (a boundary layer) signals the beginning of the transition process. Donald Coles and Steven

Barker of the California Institute of Technology made some exploratory measurements of flow in a spot of turbulence and reported their findings in 1974. They concluded, on the basis of slender and partly circumstantial evidence, that the turbulent spot in a laminar boundary layer is essentially a single large horseshoe-shaped vortex structure. Other investigators have since verified this horseshoe vortex model, but disagreement persists over certain important properties of the vortex, especially its characteristic speed of propagation.

The recent renewed interest in turbulent spot structure has been strongly influenced by coherent structure experiments in turbulent shear flows. During the past few years evidence has been accumulating to suggest that transport in turbulent shear flows is controlled by large coherent flow structures which, although they differ from one type of flow to another, all represent typical

and recognizable concentrations of transverse mean vorticity at the largest scale of the flow. In this context the turbulent spot in a laminar boundary layer provides an example of an isolated coherent structure which may have important properties in common with structures in fully developed turbulent boundary layers.

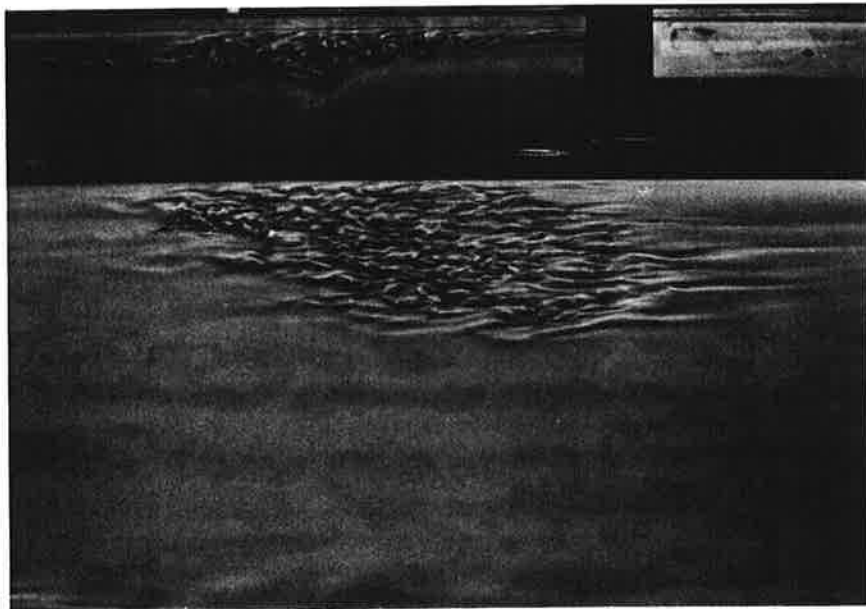
To further explore the applicability of "spot" or incipient turbulence data to the modeling of fully turbulent flow situations, Coles, Brian Cantwell, and Paul Dimotakis at Caltech recently completed a series of experiments designed to provide a kinematic description of the turbulent spot. Measurement of flow velocity components and interpretation of data are complicated by nonsteady mean flow, the three-dimensional nature of the spot, and by spot growth. This last is a serious problem since a typical spot roughly doubles its size during the time interval between the passage of leading and trailing interfaces past a

fixed probe. Since the spot is being transported with the flow, but not at the mean flow speed, it is precisely the mean or net speed of the spot that is an important unresolved issue of the Cantwell, Coles, and Dimotakis experiment.

Measurements on a flat-plate model were carried out at Caltech in the Graduate Aeronautical Laboratories in a low-speed water channel. Detailed velocity components were measured using a laser-Doppler system for the flow in the plane of symmetry of a turbulent spot. Many hundreds of "events" were recorded as turbulent spots moved past the probe volume; hence, a clearer picture of the kinematics has appeared. A similarity coordinate system was used to freeze the motion, and it was established that the main vortex in the spot moves at 77 percent of the mean fluid speed while the rear of the spot moves at 64 percent of the mean speed. Strong fluid entrainment was found to occur along the upper part of the rear interface and also near the wall in the front of the spot.

### Secondary Currents in Natural Streams and Rivers

Secondary currents in rivers and streams are circulatory currents that flow perpendicular to the direction of the main stream—across the width of the stream flow towards a bank, down the bank, across the bottom in the opposite direction to the secondary current near the surface, and up the other bank. These secondary currents contribute to bank erosion, sediment transport, and even to the formation of meanders. Albert Einstein, in one of his essays on science in *Mein Weltbild* (1933, Verlag Amsterdam), explained the cause of formation of meanders in rivers and streams on the basis of secondary currents, which he believed, however, to be caused by Coriolis acceleration due to the Earth's rotation.



**Turbulent spot.** The transition from smooth to turbulent flow in a fluid is important in many kinds of engineering systems designs. New measurements on the initial, isolated appearance of turbulence—made highly visible here by a dense suspension of aluminum flakes in the fluid—may lead to better understanding of fully developed turbulence phenomena.

Estimation of the rate of movement and redeposition of sediment is of great importance to water quality and to the management of streams, rivers, and water resources. While suspended sediment is generally considered as degrading water quality, it can have a beneficial effect too. The suspended sediment particles can absorb dissolved toxic materials and deposit them on the river bed. Also, the turbidity provided by suspended sediments limits the penetration of sunlight and, therefore, the multiplication rate of algae.

Engineers and scientists have been aware that secondary currents exist in any open channel, natural or artificial, and that they affect sediment transport. However, in the absence of feasible techniques to compute secondary currents, they have usually excluded them in studying sediment transport in open channels. As a result, their mathematical models of sediment transport have been almost exclusively one dimensional (in the longitudinal direction).

However, research recently carried out by C. L. Chiu at the University of Pittsburgh has enabled the computation of secondary currents in streams and rivers on the basis of the initial variation in longitudinal stream velocity throughout the cross section and the nonlinear partial differential equations of incompressible fluid flow. The analytical technique produced by this investigation is not only capable of computing the magnitude and direction of secondary currents, but also makes it possible to undertake the three-dimensional analysis, modeling, and simulation of various processes in streams and rivers for hydraulic and environmental projects. It has been applied and tested successfully in two different river channels: the south Beaverdam Creek, near Dewy Rose, Ga., and the Rio Grande channel near Bernardo, N. Mex. The mathematical techniques resulting from this research will now make it possible to include secondary currents in computing sediment concentration and

spatial distribution of sediment through transverse channel cross sections of streams or rivers under both steady and unsteady conditions.

Transport processes in streams and rivers of pollutants other than sediment, such as industrial solid wastes, liquids, or heat, are also affected by the three-dimensional structure of flow. The absence of a convenient mathematical technique to compute secondary currents has hindered a three-dimensional investigation of transport processes of pollutants in streams and rivers. The technique resulting from this research provides a useful methodology for undertaking these three-dimensional investigations.

### Improved Oil Recovery

As much as half of the oil in a reservoir can still remain in the ground following conventional primary and secondary recovery processes. This is a consequence of the inability of these processes to displace oil trapped in the smallest pores. Clearly, the pressing energy demands in the United States dictate that we devise more efficient recovery of our available oil resources.

Surfactant flooding is one of the more promising tertiary oil recovery techniques currently being developed. This process employs an aqueous surfactant slug followed by a water flood drive to displace the oil locked in the small pores. The role of the surfactant is to reduce the interfacial tension between the oil and flooding slug so the recovery process can penetrate the smaller pores, those inaccessible to conventional water-flooding. The only property of the oil-slug interface considered in the screening of suitable surfactants for this process has been the interfacial tension. Surfactants that effect an interfacial tension near zero were thought to be most desirable.

Under support from NSF, however, recent research at Illinois Institute of Technology (IIT) has developed ex-

perimental techniques to measure other important properties that give promise of significant improvement in the design of this tertiary oil recovery process. Darsh T. Wasan and his coworkers at IIT's department of chemical engineering are undertaking a theoretical and experimental investigation of the rheological or flow properties of fluid-fluid interfaces containing surfactants. The principal transport properties of interest are the ability of the interface to resist shear and expansion. Unambiguous, accurate measurement of such properties has become possible only in recent years. Consequently, many engineering processes involving dynamic fluid-fluid interfaces, such as surfactant oil recovery, have, in their design, neglected the potential influence of the interfacial rheological behavior.

Among the several new experimental techniques developed by the IIT group is one for obtaining the interfacial shear viscosity at a liquid-liquid interface from similar measurements on the associated liquid-gas interfaces. This technique is of considerable value for opaque liquid-liquid systems such as crude oil and aqueous surfactant solutions. In addition, these researchers have also developed a modified longitudinal wave technique for measuring the surface dilational viscoelastic properties. These new experimental techniques, along with interfacial tension, surface concentration, surface potential, and light scattering measurements, have been employed by the IIT group to explain the complex behavior of surfactant films at moving fluid-fluid interfaces.

Wasan has observed in these studies that those surfactant formulations that yield good oil recovery exhibit both low interfacial tensions and low interfacial shear viscosities. He explains that low interfacial tension between the oil and aqueous surfactant solution is necessary to ensure displacement of the oil from the porous rock. However, this low interfacial tension can also result in considerable

emulsification or dispersion of the oil in the water. The resulting emulsions can be quite stable and therefore difficult and costly to separate unless the interfacial viscosity is also low. Recent experiments at IIT have shown that surfactant formulations that ensure low interfacial shear viscosity will promote the coalescence of oil droplets and thereby decrease the emulsion stability, enhancing the formation of a continuous oil bank. Wasan has also demonstrated that the surfactant concentration that minimizes the interfacial tension may

not necessarily minimize the interfacial shear viscosity simultaneously. Hence, this research indicates that both interfacial tension and rheology must be considered in selecting surfactant formulations for tertiary oil recovery.

Continuing research at IIT is now directed towards interrelating the rheological behavior of fluid-fluid interfaces with the molecular nature of the adsorbed species. Hopefully, this knowledge will permit us to synthesize surfactant formulations that will optimize oil recovery.

structure as it affects bonding with complex solids. Furthermore, difficulties with the characterization of adsorbed surface species, particularly on complex polycrystalline materials, hinder improved understanding of phenomena associated with heterogeneous catalysis, corrosion, lubrication, and adhesion. R. W. Vaughn of the California Institute of Technology, building on contributions by W. I. Goldburg at the University of Pittsburgh and J. S. Waugh at the Massachusetts Institute of Technology, has developed and applied novel nuclear magnetic resonance (NMR) techniques for characterizing bulk and surface properties of solids. Over the past 6 years these efforts have involved advances in the theory of the dynamic interactions of nuclear spin systems and development of experimental techniques to control these interactions. As a result, the resolution of solid state NMR spectra has been improved by more than four orders of magnitude. Recent work includes developing methods to combine multiple pulse schemes with dilute spin double resonance techniques to allow detailed characterization of the structure of organic materials, particularly of surface-adsorbed species.

Many important polymeric materials are amorphous; i.e., devoid of long-range order in their structure. Although study of local molecular arrangement was difficult in the past, this situation is changing rapidly with the development of powerful new experimental techniques. For example, small-angle neutron scattering results have provided experimental confirmation to the theoretical predictions by P. J. Flory and coworkers at Stanford University that the macromolecules in amorphous polymers should have a gaussian (random) distribution of shapes. More recently, R. S. Stein and collaborators at the University of Massachusetts at Amherst used the angular dependence of X-ray scattering to show that in mixtures of two

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## Materials Research

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A principal long-range goal of NSF's materials research program is to improve understanding of the relationships between the properties and structure of materials. As the level of understanding has grown, it has become clear that exceedingly low levels of impurities (or intentional additives) and rather subtle structural factors can play major roles in determining certain properties of materials. It is not surprising, therefore, that some of the more significant advances of the past year have concerned such relationships. A key ingredient in most of these accomplishments has been the utilization of powerful, new experimental techniques, in many cases coupled with modern theoretical concepts; progress over the past year has been substantial.

For example, scientists at the University of Pennsylvania, under the leadership of C. J. McMahon, Jr., and W. R. Graham, are studying the effect of minor constituents and trace impurities on the temper embrittlement of certain chromium-molybdenum alloy steels. Through the use of Auger spectroscopy for the analysis of intergranular fracture surfaces, the

measurement of fracture energies in high vacuum, and studies of the effect of molybdenum on the kinetics of phosphorus segregation, they have clarified a number of the complex processes involved. Initially, molybdenum is in solid solution and acts as a scavenger for phosphorus. During aging at elevated temperatures, carbides containing molybdenum are formed at the expense of molybdenum-phosphorus compounds. Phosphorus is thus freed to migrate to grain boundaries, with resulting embrittlement. It appears that the key to producing embrittlement-resistant chromium-molybdenum steels is to minimize molybdenum-carbon formation. One possibly practical approach is to alloy the steel with small amounts of elements such as vanadium or columbium that form carbides that are more stable than those formed with molybdenum, leaving the molybdenum free to find and combine with phosphorus.

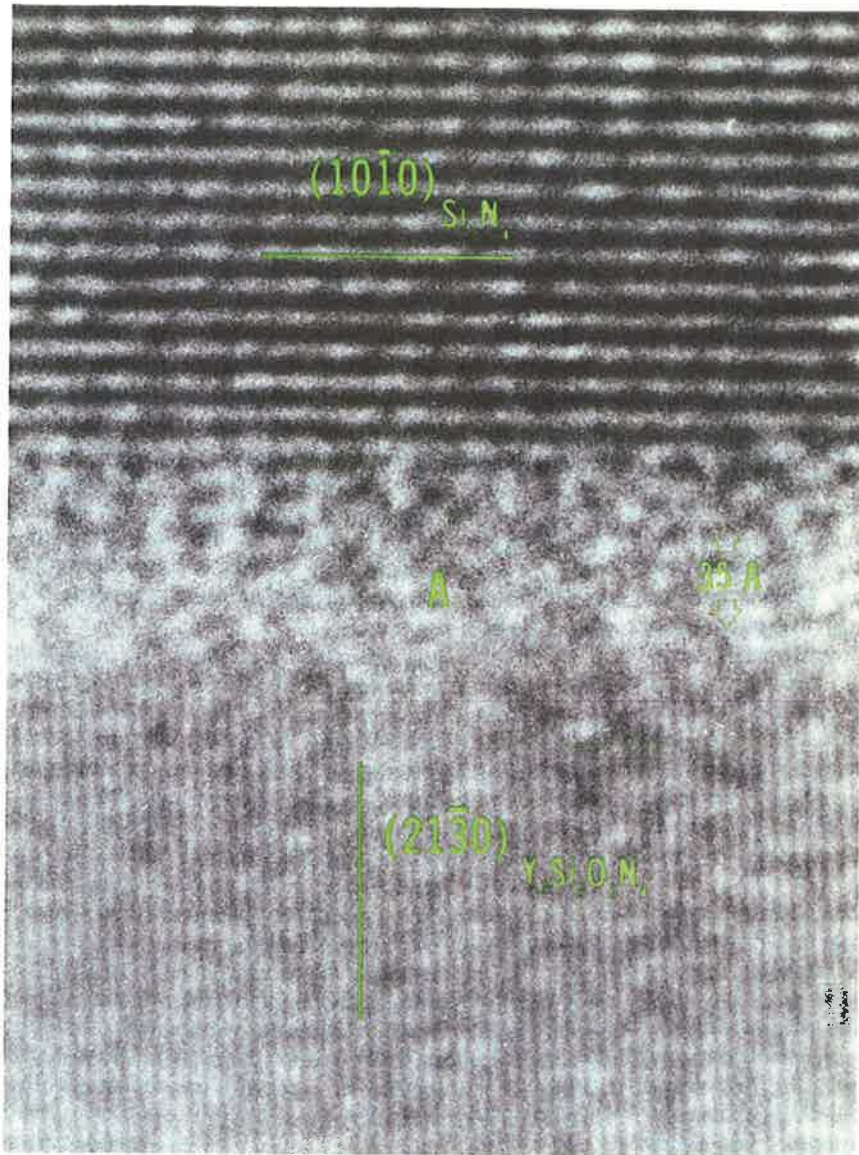
A major difficulty in developing new engineering materials, as well as optimizing properties of those presently available, lies in obtaining detailed information on molecular



polymers, each type of macromolecule is also gaussian.

An open question for some time, however, has been whether molecular components of so-called amorphous polymers can exhibit some aggregative, "supermolecular" structure. Several years ago G. S. Yeh at the University of Michigan reported electron microscopy studies that suggested the existence of aggregative "nodules" 30 to 150 angstroms in size in amorphous polymers. Recent work by P. Geil at Case Western Reserve University has produced the first wholly amorphous linear polyethylene. Surprisingly, thin films of this new form of polyethylene displayed a nodular 100-angstrom structure. Thus, the question of possible order in "amorphous" polymers must again be considered.

The effect on the mechanical strength of ceramics of impurities and secondary phases at grain boundaries is an important scientific and technological problem. A current example is silicon nitride ( $\text{Si}_3\text{N}_4$ ), under development for turbine components. Identification of the composition and structure of the grain boundary phase(s) has now been accomplished by D. Clarke and G. Thomas at the University of California, Berkeley, using sophisticated techniques of electron microscopy, including rocking beam microdiffraction, high-resolution dark-field imaging, X-ray microanalysis, lattice imaging, and stereomicroscopy. The most difficult and important advance in this grain boundary structure study was confirmation of the presence of a 35-angstrom-thick layer of amorphous material between grains of the silicon nitride and neighboring grains of  $\text{Si}_3\text{Y}_2\text{O}_3\text{N}_4$  (silicon nitride doped with yttrium oxide) added to bring the material up to the required density/strength characteristics. The identification of the amorphous material pinpointed the cause of a weakening of the grain boundaries at high temperatures.



**Zone of weakness in a high temperature structural ceramic.** This high resolution electron photomicrograph of the boundary between grains of silicon nitride ( $\text{Si}_3\text{N}_4$ ) and silicon nitride doped with yttrium oxide ( $\text{Y}_2\text{Si}_3\text{O}_3\text{N}_4$ ) shows a zone at A, about 35 angstroms thick, of noncrystalline material. This amorphous zone is thought to contribute to weakening of the grain boundaries at high temperatures. (Photo by D. Clarke and G. Thomas/University of California, Berkeley)

### Understanding Hydrogen Embrittlement of Metals

Catastrophic failure of metal structures can occur through the introduction of hydrogen. Although such

"hydrogen embrittlement" has long been recognized, the need to understand it has suddenly increased with the creation of new energy technologies. Recent research has identified several mechanisms of

hydrogen embrittlement, including phase transformations, development of unstable plastic shear zones, interaction with impurities segregated at grain boundaries, and lowering the energy barrier for crack propagation. These studies are also illuminating fundamental relations between atomic structure, defects, and mechanical properties of solids.

Experiments at the University of Illinois by C. Altstetter, H. K. Birnbaum, H. Fraser, E. N. Pugh, and R. Yeske indicate that crystallographic phase transformations can occur in certain stainless steels when stress is applied. Hydrogen then enters the metal more readily, and the fracture becomes a low ductility-cleavage. Other stainless steels believed to be stable against phase transformations exhibit failure only in much more aggressive environments.

At Ohio State University and Battelle Memorial Institute, J. Hirth and coworkers have determined that hydrogen promotes unstable plastic flow. Shear is localized in a thin sheet of material where the formation of voids is enhanced and fracture made easier.

Additional collaboration between groups at Ohio State and Battelle has refined computer modeling of the atomic interactions at a crack tip. A new analysis of the elastic displacement field has been developed and applied to the boundary between a crack tip and the medium. Computer simulation has supported an earlier suggestion that, because of the atomic periodicity of its structure, the total energy of a solid should vary periodically as a crack propagates through it. The model also predicts that hydrogen at the crack tip lowers the resulting energy barrier for crack propagation.

An unaged alloy steel, exposed to hydrogen, cracks by a transgranular mode at very high stress intensity levels, whereas intergranular cracking at low stress intensity occurs in aged specimens, according to C. J. Mc-

Mahon, Jr., at the University of Pennsylvania. By Auger electron spectroscopy, he found phosphorous, nitrogen, and silicon impurities at the grain boundaries. If segregation of these critical impurities can be prevented, resistance to failure in hydrogen might be improved.

Stainless steels retain large amounts of hydrogen if the metal is cold-worked, reports N. Fiore at Notre Dame. He proposes that a strong interaction between dislocations and dissolved hydrogen is responsible. Field tests of specimens in natural gas containing a hydrogen sulfide impurity have demonstrated that cold-worked stainless steels remain strong. This result suggests that if hydrogen can be trapped at innocuous sites within a metal, resistance to embrittlement can be increased.

Theorists have tried to describe analytically the potential well in which hydrogen oscillates in a metal, but the limited data available from changes in second-order elastic constants alone have not permitted a detailed comparison. C. Wert at the University of Illinois and collaborators at Rockwell International have now measured third-order elastic constants, temperature dependence of second-order constants, thermal expansion coefficients, and changes in the lattice constant of niobium with the addition of hydrogen in solid solution. Careful evaluation of proposed interatomic potentials should now be possible.

### Superconductivity in Ternary Compounds

Many important applications of superconductivity have been limited by the magnitude of the magnetic fields in which the superconductor retains its zero resistance property. Above a certain level of magnetic field—known as the upper critical field—the material is no longer superconducting. In general it has been found that the presence of magnetic

ions in a superconducting material results in a drastic deterioration of the superconducting properties. Hence, considerable interest was aroused by a recent discovery that rare earth ions in ternary (three-element) Chevrel phase superconductors cause virtually no reduction in the superconducting transition temperature but cause a surprisingly large increase (about 100 kilogauss) in the upper critical field. A mechanism not heretofore observed is operating in these ternary materials.

C. W. Kimball at Northern Illinois University, in collaboration with F. Fradin, B. Dunlap, and G. Shenoy of Argonne National Laboratory, has used a combination of Mossbauer spectroscopy and nuclear magnetic resonance to show how magnetic ions can lead to the enhancement of the magnetic properties of superconducting materials. The model of the microscopic behavior of the magnetic polarization in the compound  $\text{Sn}_{0.05}\text{Eu}_{0.05}\text{Mo}_6\text{S}_8$ , a typical high transition temperature, high upper critical field Chevrel phase, is one in which the europium (Eu) ions interact strongly with only part of the conduction electrons (the highly delocalized s-electrons) and only weakly with those principally involved in the superconductivity (the molybdenum d-electrons). The molybdenum d-electrons are more localized and also shielded from the europium ions by sulfur neighbors; consequently, the superconducting transition temperature is not strongly affected by the presence of the magnetic ions. The principal effect of the europium ions in the presence of the magnetic field is the alignment of the rare earth magnetic moments, which causes a polarization of the s-band. This polarization is transferred to the molybdenum site but oppositely directed to the applied field so that a partial cancellation is effected. Hence, the external field can be increased to a larger value before the effective field felt by d-electrons becomes large enough to destroy superconductivity.



Many energy technologies (e.g., fusion reactors and new forms of mass transit) will require high magnetic fields. The discovery of this mechanism for magnetic field cancellation opens up whole new areas of research. B. Matthias of the University of California, San Diego, a pioneer in the discovery of new superconducting materials, believes that these unique properties are indigenous to the ternary materials. Another particularly interesting example studied by Matthias is  $\text{ErRh}_4\text{B}_4$  (a rare earth intermetallic compound), which becomes superconducting below  $9^\circ\text{K}$ , but loses its superconducting properties below  $1^\circ\text{K}$  when it forms a magnetic state.

Theoretical calculations of the electronic structure responsible for this behavior are extremely difficult because of the large number of atoms per unit cell (18 for these compounds). However, recent developments in computational techniques, together with advances in the speed of computers, have made such calculations feasible. This has been shown by a recent paper by T. Jahlborg, A. J. Freeman, and T. J. Watson-Yang of Northwestern University and Argonne National Laboratory. They have been able to calculate the energy band structure of  $\text{ErRh}_4\text{B}_4$  using self-consistent local density theory—a computational tour de force! The results of this calculation in describing the shape of the electronic charge density, for example, have gone a long way in elucidating the interactions involved; it will form the basis for the future analysis of these important compounds.

### Electronic Defect Structure of Amorphous Semiconductors

Scientists at the Massachusetts Institute of Technology, Harvard University, and the University of Chicago have recently made signifi-

cant progress in understanding the electronic properties of amorphous semiconductors on the basis of the intrinsic defects present in these unusual materials. Unlike crystalline semiconductors, which are well understood and which form the basis for the modern electronics industry, amorphous materials have a disordered atomic structure that freezes in when they are cooled rapidly from the liquid or vapor phase through the glass transition temperature.

Two major classes of covalently bonded amorphous semiconductors have been studied extensively: those such as germanium or silicon, in which the bonding between the atoms is tetragonal (fourfold), and those containing a large fraction of chalcogen atoms, such as sulfur or selenium, which bond in twofold configurations. The tetrahedrally bonded amorphous semiconductors have considerable potential as inexpensive materials for large-scale photoelectric solar energy conversion, while the unique optical and electrical behavior of the chalcogenide glasses make them attractive for switching and other electronic device applications.

Marc Kastner and David Adler at the Massachusetts Institute of Technology, in collaboration with Hellmut Fritzsche from the University of Chicago, have been able to explain the widely differing behavior of these two classes of disordered material in terms of a simple model for the electronic structure of covalent semiconductors. In each class, electronic transport is controlled by a particular intrinsic defect center arising from the imperfect atomic bonding inherent in the disordered structure.

For the chalcogenide glasses these workers have shown that the lowest energy defect is a "valence alternation pair" (VAP) consisting of a positively charged, threefold coordinated chalcogen and a negatively charged, singly coordinated chalcogen. These VAP's have an unusual property in that they set the electronic Fermi level

(separating occupied from unoccupied electronic states in a metal or semiconductor) near the center of the energy gap without forming any new electronic states near the Fermi level itself. This means that, owing to the large defect concentration, the electronic properties cannot be effectively modified by doping with impurities as crystalline semiconductors can. At the same time, the material is unable to support electrical conduction through hopping of electrons from one VAP to another. The Kastner-Adler-Fritzsche model can account for a variety of novel effects observed in the chalcogenide glasses, including the absence of an electron spin resonance signal from the defects, the photoluminescence behavior and its decay, and the electronic switching behavior under high applied electric fields.

In the tetrahedrally bonded semiconductors the principal defect, formed when an atom is incompletely bonded to its neighbors, is a so-called "dangling bond." Although the dangling bonds also set the Fermi level near the center of the energy gap, electrical conduction is able to proceed by hopping of electrons from one defect center to another. Moreover, these defects can be neutralized by the addition of hydrogen atoms to remove the dangling bond, thus revealing the intrinsic electronic energy band structure of defect-free amorphous material.

William Paul of Harvard University has been studying this question for several years with considerable success. Recently he has shown that it is possible to obtain either n- or p-type amorphous silicon by doping the hydrogen-neutralized material with boron or phosphorus impurities, respectively, just as in the case of crystalline silicon. Although much remains to be learned about both the basic science and the technology of amorphous silicon devices, the potential significance of this work for solar energy conversion is intriguing.

## Determination of Interatomic Distances by EXAFS

Synchrotron radiation has many attributes, including a continuous spectrum ranging from the visible to the hard X-ray region, which make it especially useful as a new tool for the study of a wide variety of materials and phenomena. It is the availability of the high-intensity continuous X-ray spectrum from a synchrotron radiation source that allows many experiments to be done that previously were not considered feasible or simply took too much time.

One of the most exciting developments is the use of synchrotron radiation for the precise determination of interatomic distances and of local atomic arrangement surrounding specific atoms. The X-ray absorption of the element in the host material under investigation is measured from its characteristic absorption edge out to higher energies. Typically, the absorption is measured over a range of energies extending to a thousand electron volts above the absorption edge of that element. The resulting oscillatory spectrum is known as the X-ray extended absorption fine structure (EXAFS) of the

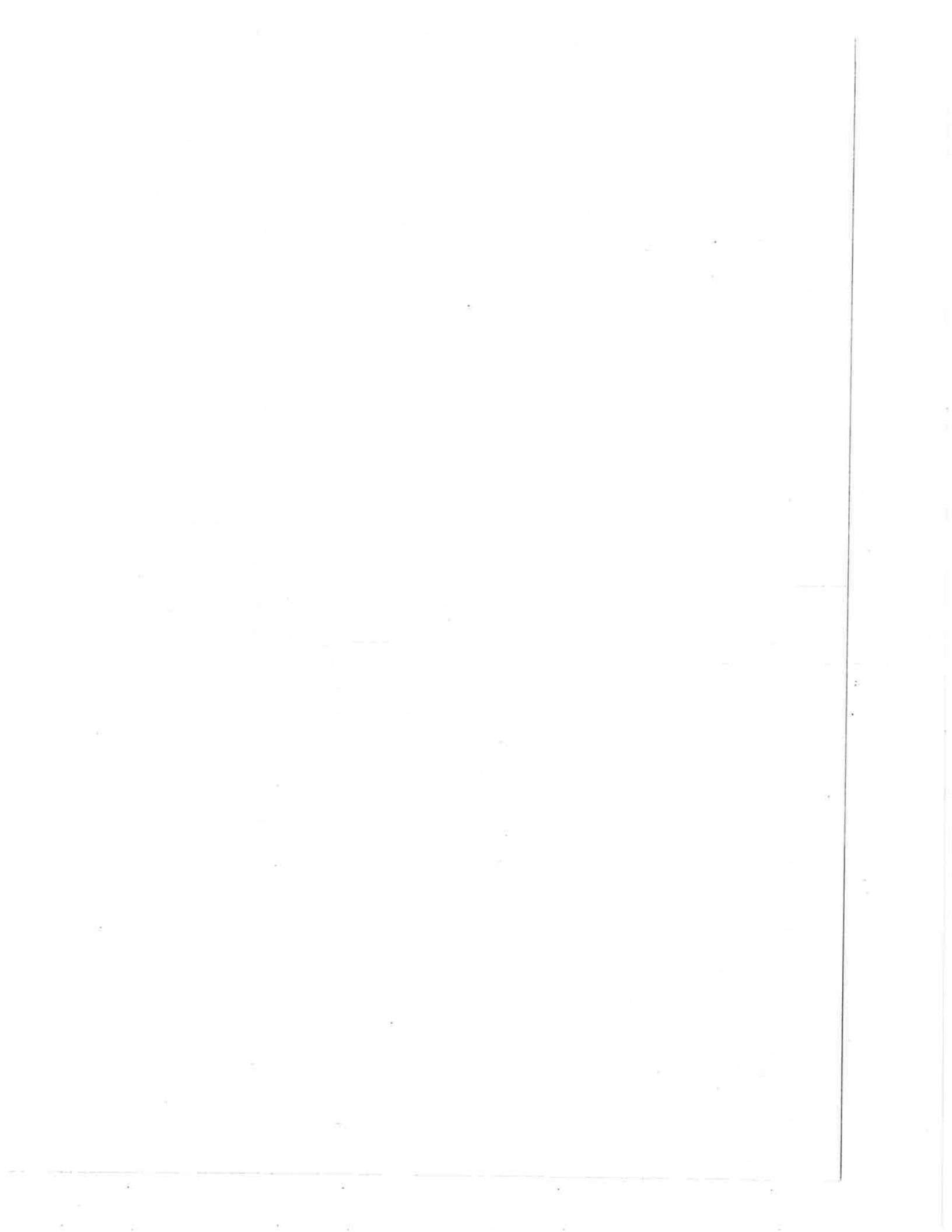
element. Recent work has put the theoretical understanding of the EXAFS on a very firm foundation so that EXAFS can now be used as a tool for investigating the properties of matter.

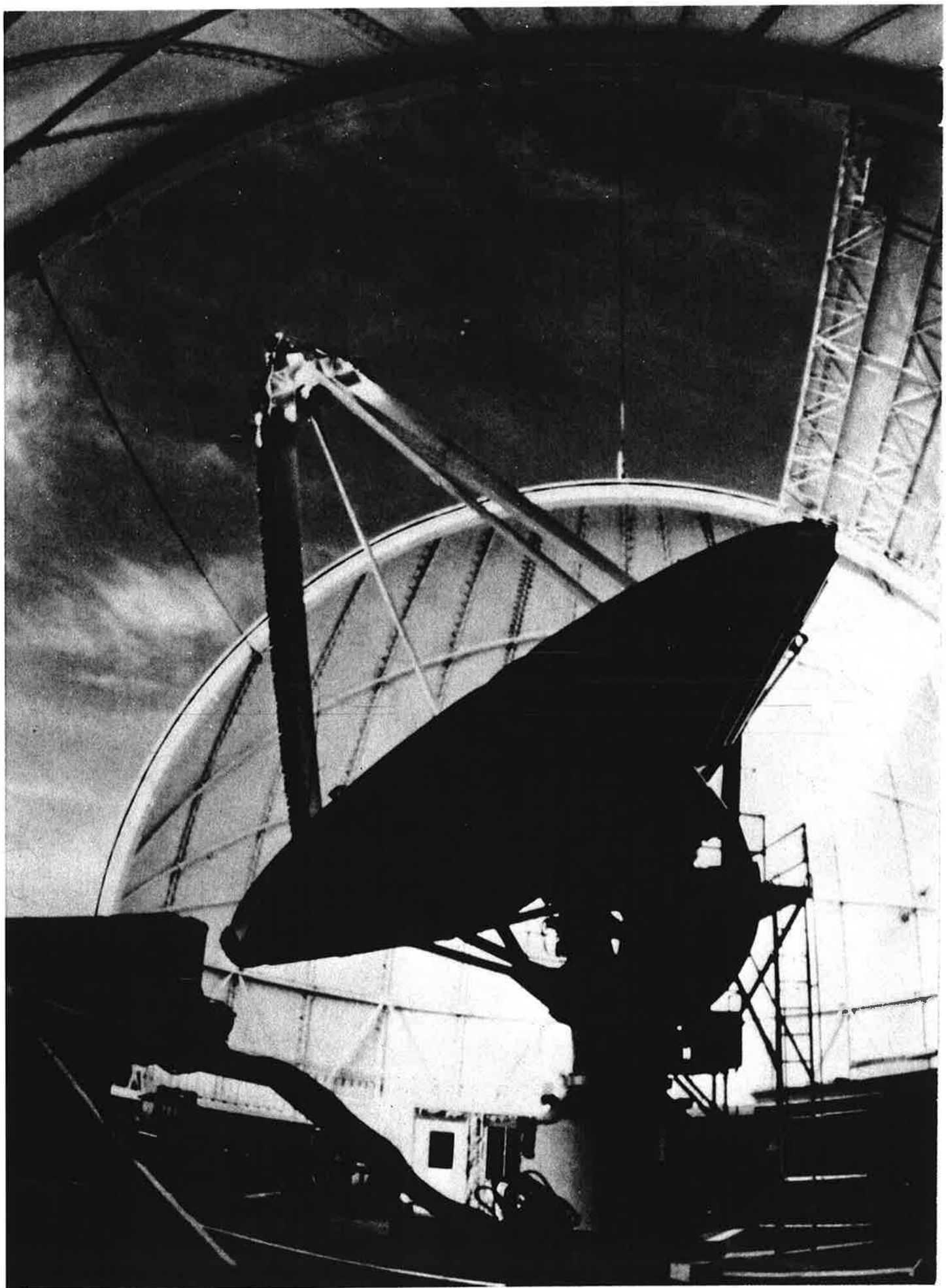
Glasses, for example, are characterized by short-range order in the coordination and interatomic distances of atoms but lack the long-range periodicity of crystalline solids. Structural models that have been proposed include both random-network and microcrystalline models. F. W. Lytle of the Boeing Company and E. A. Stern and D. E. Sayers of the University of Washington have used EXAFS to analyze structural disorder in glassy and crystalline germanium dioxide. The similarity of the germanium-oxygen and germanium-germanium distances between crystalline and amorphous germanium dioxide is consistent with earlier X-ray measurements. However, these earlier measurements did not yield information beyond the nearest neighbor shell. The EXAFS study rules out the microcrystalline model since crystalline regions would give a different distribution of bond distances than those measured.

The University of Washington group has also used the EXAFS tech-

nique to study the chemical state, structure, and location of bromine molecules adsorbed on graphite. They have determined that at very low coverage, one of the bromine atoms is fixed to the graphite surface with the other end of the molecule being free to flop around. At high coverages of the graphite surface, the molecules become reoriented so that the molecular axes lie parallel to the surface. Thus, EXAFS becomes a useful technique for surface studies—especially since it is sensitive to coverages of less than a monolayer.

Experiments have been carried out at Stanford University on nitrogenase—the enzyme that contains molybdenum and iron and which is important in leguminous plants in the conversion of molecular nitrogen to ammonia. Very little is known about the precise structure or the chemical function of nitrogenase, but EXAFS experiments indicate that the molybdenum atoms are surrounded by sulfur ligands. These data can be used to determine the ligand-molybdenum distance and how this changes with oxidation. Thus, EXAFS can be used to determine the atomic environment of an isolated metal atom in a complex macromolecule of unknown structure.





# Astronomical, Atmospheric, Earth and Ocean Sciences



The main goal of NSF's program in the Astronomical, Atmospheric, Earth, and Ocean Sciences is to increase our knowledge of the natural environment both on Earth and in space. This goal is reflected in the overall objectives of the various programs: to obtain new knowledge in the astronomical and atmospheric sciences over the entire spectrum of physical phenomena; to provide a better understanding of the physical and chemical makeup of the Earth and its geological history; to obtain further insight into the ocean's composition, structure, and behavior and on the effects of human activities on the ocean environment; and to advance knowledge of the natural phenomena and processes in the polar regions.

NSF is also responsible for the U.S. Antarctic Program, which supports the goals of the Antarctic Treaty and maintains a U.S. presence and leadership in Antarctica based upon cooperative scientific programs. In this context NSF has the overall management responsibility for planning, funding, and implementing the program, which includes substantial logistics and international components.

More than two-thirds of the Federal support for ground-based astronomy in the United States is provided by the Foundation. This support is in the form of research grants to universities and colleges and through contracts with university consortia that manage

**Table 2**  
**Astronomical, Atmospheric, Earth, and Ocean Sciences\***  
**Fiscal Years 1975, 1976, Transition Quarter**  
**(July 1-Sept. 30, 1976), and 1977**

(Dollars in Millions)

	Fiscal Year 1975		Fiscal Year 1976		Transition Quarter		Fiscal Year 1977	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Astronomy .....	181	\$ 10.93	201	\$ 11.13	70	\$ 4.67	222	\$ 13.48
Solar Eclipse Support .....	—0—	—0—	1	.06	—0—	—0—	—0—	—0—
Atmospheric Sciences .....	264	13.82	237	14.91	49	2.82	276	17.66
Global Atmospheric Research Program .....	62	4.04	68	3.81	10	1.00	67	4.46
Climate Dynamics .....	10	1.00	31	1.98	16	1.00	59	3.97
Earth Sciences .....	296	12.97	296	15.29	117	4.23	325	16.26
Ocean Sediment Coring Program .....	6	10.50	5	11.83	1	3.50	4	12.80
Oceanography .....	327	15.28	320	15.65	89	4.54	322	17.70
International Decade of Ocean Exploration .....	159	14.78	179	15.42	26	3.38	190	17.16
Oceanographic Facilities and Support .....	86	20.64	70	16.01	14	1.00	69	18.39
U.S. Antarctic Program .....	122**	25.90	106**	48.58***	89**	13.43	115**	45.29
Arctic Research Program ..	35	3.63	46	3.62	7	1.30	58	4.82
<b>Total .....</b>	<b>1,548</b>	<b>\$133.49</b>	<b>1,580</b>	<b>\$158.29</b>	<b>488</b>	<b>\$40.87</b>	<b>1,707</b>	<b>\$171.79</b>

\* Excludes National Research Centers.

\*\* Science Awards. Excludes operations support awards.

\*\*\* Includes \$18.0 million for procurement of two ski-equipped aircraft.

SOURCE: Fiscal Years 1977, 1978, and 1979 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

the NSF-supported National Astronomy Centers. Among the significant events in fiscal year 1977 were development and implementation of new infrared and millimeter-wave telescopes; improved instrumentation for existing telescopes to enable astronomers to extend their observations of quasars and other very faint objects farther into deep space; initial operation by radio astronomers of 9 of

the eventual 27 antennas of the Very Large Array (VLA); and discovery of what astronomers believe may be a solar system being formed around another star.

The programs in atmospheric sciences provide more than half the support for basic atmospheric research in the Nation's universities, as well as support for the National Center for Atmospheric Research

**Table 3**  
**Astronomical, Atmospheric, Earth, and Ocean Sciences**  
**National Research Centers**  
**Fiscal Years 1975, 1976, Transition Quarter**  
**(July 1-Sept. 30, 1976), and 1977**

(Dollars in Millions)

	Fiscal Year 1975	Fiscal Year 1976	Transition Quarter	Fiscal Year 1977
National Astronomy and Ionosphere Center .....	\$ 3.20	\$ 4.05	\$ 1.10	\$ 3.90
Kitt Peak National Observatory .....	7.68	8.40	2.15	8.70
Cerro Tololo Inter-American Observatory .....	2.95	3.45	.90	3.50
National Radio Astronomy Observatory .....	19.30	21.55	3.50	21.80
National Center for Atmospheric Research ..	17.45	23.83	4.84	23.04
Sacramento Peak Observatory .....	*	*	*	.80
<b>Total .....</b>	<b>\$50.58</b>	<b>\$61.28</b>	<b>\$12.49</b>	<b>\$61.74</b>

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

SOURCE: Fiscal Years 1977, 1978, and 1979 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

(NCAR) and its associated National Scientific Balloon Facility. Important research highlights this past year include: initiation of a 2-year effort to generate in-depth information on the chemistry of the troposphere, both in its natural and perturbed states; significant new insights into the pivotal role that nitric oxide plays in the atmosphere; use and evaluation of extensive data sets from the Global Atmospheric Research Program's Atlantic Tropical Experiment (GATE); and new knowledge of the role of solar and planetary cycles in existing climatic data. The reduction and analysis of the tremendous amounts of data being generated by several of these efforts will be assisted greatly by the installation of a new fifth-generation computer at NCAR.

In earth sciences, investigators continue the testing and evaluation of the plate tectonics model. This concept, which describes the Earth's surface features in terms of large crustal plates and their movements, has provided a credible working model for the Earth as a unit and may explain phenomena such as the distribution of

earthquakes, volcanoes, and some ore deposits. Supporting evidence comes from diverse subfields such as marine geology, seismology, gravity, and stratigraphy. But, although the theory has provided a pragmatic model, it still requires much additional investigation, both observational and theoretical.

The continuing goal of NSF's ocean research programs is to improve understanding of the nature of the ocean, its influence on human activities, and man's impact on the marine environment. Significant progress toward this goal is being

made through the support of large-scale, multidisciplinary, international field projects that focus on environmental forecasting, environmental quality, seabed assessment, and living resources, and through individual research projects for developing basic knowledge of the oceans, their contents, and the sea floor. Contributing directly to these research efforts, NSF provides most of the support for 29 research vessels, a number of specialized facilities, and the development of new instrumentation to enhance shipboard research capabilities.

The Foundation is also one of several agencies able to support research in the Arctic. Based on data gathered during the Arctic Ice Dynamics Joint Experiment (supported jointly by NSF and the Office of Naval Research), scientists now have available the most complete documentation to date of sea ice motion. Cores taken from the Greenland Ice Sheet and changes in ice sheet sizes are providing more information on past climatic fluctuations. The processes and resources of the Bering Sea shelf are being studied to provide guidance on how best to manage the living resources there.

In Antarctica, discoveries of meteorites gave investigators clues to the history of the solar system. Global atmospheric studies are continuing because trends in Antarctic temperature have global implications, and the study of polar ice cores is helping to determine past climates.

## Astronomy

The Foundation, as lead agency for Federal support of ground-based astronomy in the United States, accounted for more than two-thirds of that support in fiscal year 1977. Research was funded at over 80 universities, university observ-

atories, and private and federally owned observatories. Although many astronomers are at institutions without research-quality telescopes, the extensive visiting scientist programs at the NSF-supported National Astronomy Centers and the availabili-

ty of the telescopes at some university observatories enable them to perform forefront research.

Fiscal year 1977 was the first full year of NSF support of the Sacramento Peak Observatory (SPO), which had previously been operated by the U.S. Air Force. Following recommendations by a specially convened advisory committee, SPO is now developing a strong visiting scientist program. The program will enable solar astronomers with excellent research projects to compete for observing time on the solar tower telescope and other telescopes.

In addition to supporting five National Astronomy Centers and making grants for astronomy research, NSF also assists universities in developing state-of-the-art telescopes and instrumentation. An example is the Five College Radio Observatory's new millimeter-wave telescope near Amherst, Mass. This 13.5-meter-diameter (45-foot),

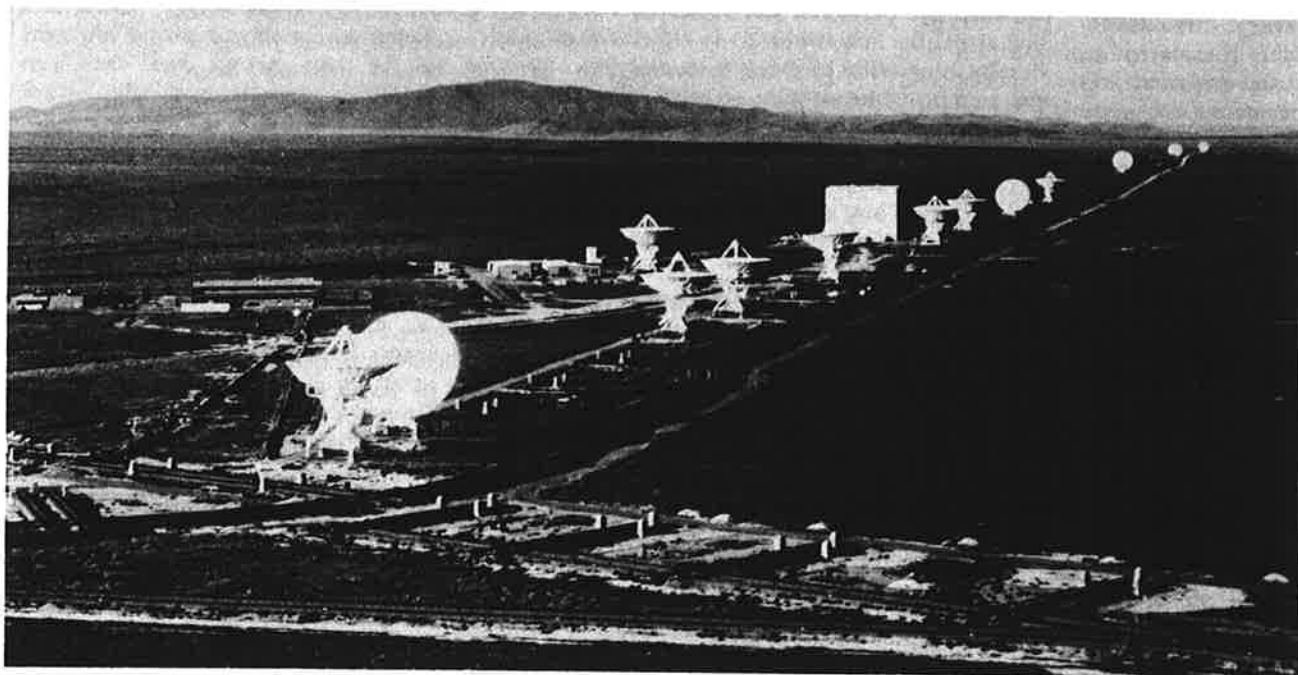
radome enclosed, aluminum paraboloid antenna equipped with advanced receivers is the most accurate millimeter-wave telescope of its size in the world and will be used primarily to detect and study interstellar molecules.

The new University of Wyoming 2.3-meter (90-inch) infrared telescope is a project jointly funded by NSF and the State of Wyoming. The primary mirror of this instrument, one of the world's largest infrared telescopes, was installed in its dome on Jelm Mountain, Wyo., in September 1977. It will be well equipped with the specialized spectrometers and other detectors necessary for observing infrared radiation from stars, nebulae, and planets.

These two most recent university telescopes emphasize a trend in astronomy to observe in all regions of the electromagnetic spectrum. Discoveries that would not have been possible with "visible light" optical

telescopes or the traditional centimeter-wave radio telescopes are now possible. In the millimeter-wave region, users of the National Radio Astronomy Observatory's 10.8-meter-diameter (36-foot) telescope located on Kitt Peak in Arizona have led the field in discovering new interstellar molecules. To date, a total of 40 different molecules have been discovered in the gas and dust clouds of deep space with this instrument. Recent discoveries include ketene ( $\text{H}_2\text{C}_2\text{O}$ ) and ethyl cyanide ( $\text{CH}_2\text{CH}_2\text{CN}$ ). These and other interstellar organic molecules could well provide the key to the origin of life in the universe.

New techniques and better telescopes have allowed optical and radio astronomers to extend their observational range into the far reaches of space. The 4-meter (160-inch) Cerro Tololo Inter-American Observatory optical telescope, located at one of the world's prime observing sites, is now



**Coming on line.** By 1981 the Very Large Array will comprise 27 antennas operating together as the world's most sensitive radio telescope. Astronomers conducted research with nine operational antennas in fiscal year 1977. (The distance between the nearest and farthest antennas in this view along the southwest leg of the wye-shaped track is 7.6 kilometers.)

beginning to report observations of very faint objects down to the 24th magnitude. Using a spectrographic technique to search for distant objects, astronomers have found some 400 new quasar candidates. As determined by the redshift of their emitted light, some of these objects are receding from us at rates up to 95 percent of the speed of light.

As of September 1977, 9 of the planned 27 antennas of the Very Large Array were in use by radio astronomers. When used simultaneously, these nine antennas form an interferometer with twice the resolving power of comparable instruments in the United States. Detailed maps of a planetary nebula have recently been obtained.

Although the centers of distant galaxies are observable through telescopes, the dust-shrouded center of our own Milky Way galaxy is opaque to visible light. As such, its nature and energetic processes known to be going on there have remained a relative mystery. However, the light-obscuring material is transparent to infrared and radio waves, and optical astronomers are beginning to explore the region with telescopes modified for infrared observing. Radio astronomers are also probing the galactic core and last year employed a Very Long Baseline Interferometer (VLBI) to identify a large but relatively compact bright object at that location. The object was 200 astronomical units (an astronomical unit is the mean distance between the Earth and the Sun) in diameter. The VLBI network consisted of three radio telescopes located in Massachusetts, West Virginia, and California.

### A Planetary System In Formation

It was once believed that our solar system was formed in a cataclysmic, and extremely rare, collision between two stars. It is now held, however,

that the formation of planetary systems is a frequent and natural byproduct of the formation of stars from clouds of interstellar gas and dust. Astronomers have long hoped to confirm modern theories of the origin of planetary systems by observing a planetary system in the process of being formed. Recently, R. I. Thompson and P. A. Strittmatter of the University of Arizona collaborated with E. F. Erickson, F. C. Witteborn, and D. W. Strecker of the National Aeronautics and Space Administration's Ames Research Center to obtain new observations of the peculiar object MWC 349. They believe these observations reveal MWC 349 to be a star surrounded by a preplanetary disk of matter.

The astronomers recorded visible and infrared spectra of MWC 349 to measure the strengths of characteristic emission lines of hydrogen. For a region of hot, low-density gas, the strengths of these lines can be predicted. The difference, then, between the predicted and measured line strengths is attributed to extinction by interstellar particles. Knowing the amount of interstellar extinction, the astronomers can use the measured strength of a particular hydrogen line to find the spectral type of the central star of MWC 349 and the amount of light it produces in the visible part of the spectrum.

It turns out that the amount of visible light observed is far more than the amount that should be coming from MWC 349. The Arizona astronomers attribute the excess light to a disk of gas around the star. To produce the observed visible light, the matter in the disk would have to be heated by falling onto the star at the rate of about one-thousandth of a solar mass per year. The eightfold drop in visible light from MWC 349 during the past 40 years implies that the total mass of the disk is about one-hundredth of the mass of the Sun. This estimate refers only to the central portion of the disk where the

material has become hot enough to produce large amounts of visible light. There may be additional material farther out in the disk and too faint to be seen. The astronomers believe that the disk may have contained significantly greater mass at an earlier epoch. Some of this material may already have condensed into planets. If so, this would be the first observed case of the formation of a solar system.

### New "Days" for Uranus and Neptune

At a time when spacecraft exploration of the outer planets is becoming a reality, basic data on the outer planets of Uranus and Neptune are still sparse. Even the long-quoted rotational periods (i.e., the length of a "day" on a planet) were recently called into question. High-resolution imagery of Uranus showed the planet to be much less oblate than expected from its previously measured rotational period of 10.8 hours, and Neptune's rotational period (thought to be 15.8 hours) had not been measured spectroscopically since 1930.

Two astronomers at Kitt Peak National Observatory have new evidence showing that the rotational periods are indeed substantially longer than previously thought. Using the echelle spectrograph on the 4-meter Mayall Telescope, Sethanne Howard Hayes and Michael J. S. Belton measured periods of  $24 \pm 3$  hours for Uranus and  $22 \pm 4$  hours for Neptune. Their technique is based on the Doppler shifts in reflected solar spectral lines observed across the face of a planet. Each discrete line appears bluer on the approaching side of the planet than on the receding side. As a result, the lines recorded on a spectrogram are tilted by an amount proportional to the planet's rotational speed.

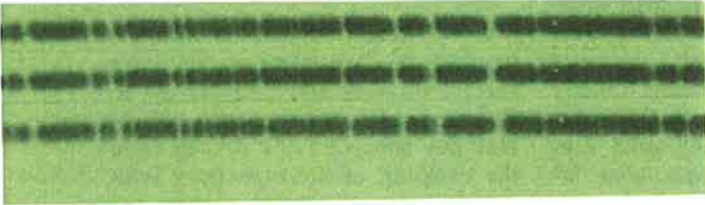
Hayes and Belton found that the precision of the spectroscopic method



PA

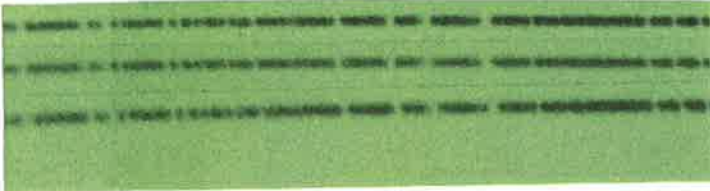
## URANUS

20°  
120°  
170°



## NEPTUNE

45°  
90°  
160°



## MOON



**Day lengths.** Spectrograms of the planets Uranus and Neptune, made with the 4-meter telescope at Kitt Peak, show reflected solar spectral lines for different measuring angles of the planets' images. The degree of tilt of the lines, compared to those for the Moon with its known speed of rotation, gives measures of the speeds of rotation of the planets.

is severely limited by atmospheric turbulence and other observational uncertainties. The turbulence in the Earth's atmosphere tends to decrease the observed tilt in the planet's spectrum. Especially for Neptune, the atmospheric correction is large and uncertain; the estimated errors in the periods reflect this uncertainty.

The question is certainly not resolved, though. Two other groups of researchers have recently derived

periods of 12.3 hours and 15.6 hours for the rotation of Uranus. However, dynamical evidence supports the result of Hayes and Belton in that the shapes of both Uranus and Neptune are compatible with the longer periods. The flatness of a planet is determined in part by its spin, and hence can be used to predict the rotational speed. For Uranus, the oblateness implies a rotational period greater than 21 hours; for Neptune

the predicted "day" is 15.4 hours. Although Neptune's predicted and observed periods disagree, Hayes and Belton feel that the difference can be explained by the uncertainty in their seeing correction. They suspect that their 22-hour period is too long and that the true value lies between 15 and 18 hours.

The new results differentiate Uranus and Neptune from the other two giant planets, Jupiter and Saturn, which have 10-hour days. Uranus and Neptune are known to be smaller, less oblate, and more slowly spinning than their inner neighbors. These differences hint at variations in the planet-formation process.

### Dips in the Cosmic Background

Using the 10.8-meter (36-foot) radio telescope of the National Radio Astronomy Observatory at Kitt Peak, George Lake of Princeton University and Bruce Partridge of Haverford College have detected "dips" in the intensity of cosmic microwave background in the direction of three clusters of galaxies.

The observed cosmic background is equivalent to the radiation that an ideal radiating body at a temperature of 2.7° K (-454.9° F) would emit. It emanates almost uniformly from all directions across the sky and is conventionally interpreted as the relic radiation from the "Big-Bang" explosion that formed the universe. Although the high degree of uniformity of this background supports the big bang theory, skeptics have often suggested that the radiation might have a more mundane explanation.

R. A. Sunyaev and Ya. B. Zel'dovich of the U.S.S.R. Institute of Applied Mathematics first predicted that the cosmic background would show dips in intensity in the direction of some clusters of galaxies. This prediction was based on the assumption that the background was indeed cosmic, so

that it originated "behind" any object in the universe. Further, they argued that strong X-ray emission associated with many clusters of galaxies was due to the presence of an enormous amount of very hot gas among the galaxies in these clusters. The hot gas would scatter the cosmic background photons, heating them slightly. Somewhat paradoxically, this heating results in a reduction in the intensity of the cosmic background at low frequencies because the total number of photons is conserved.

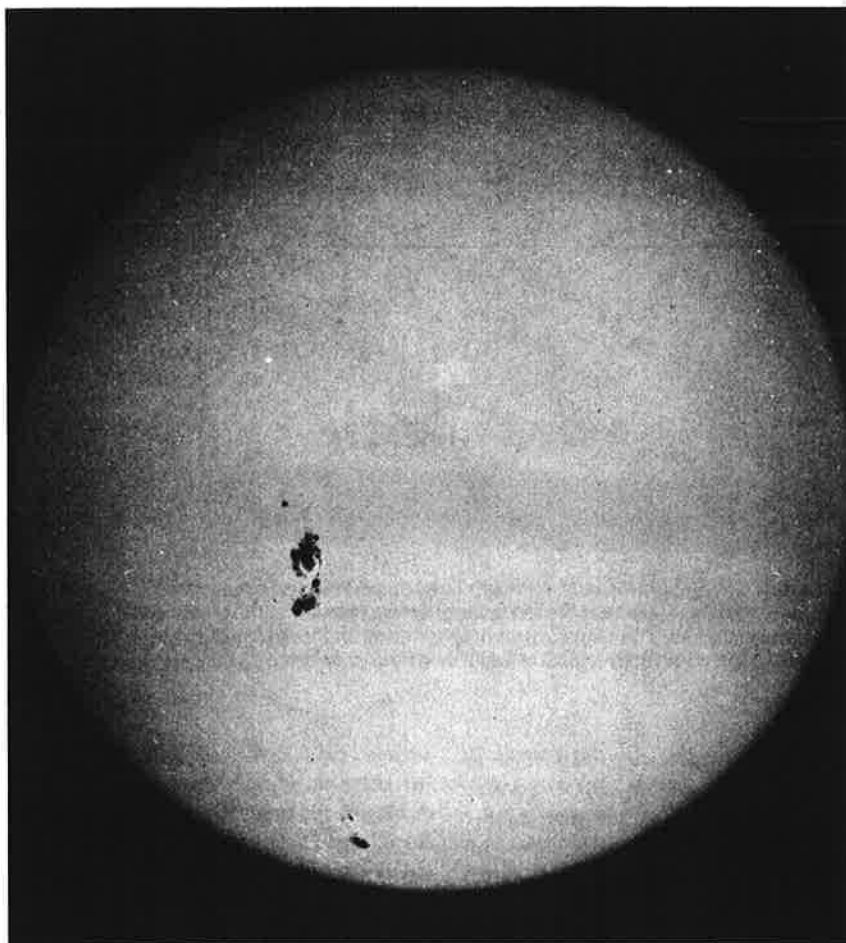
Detections of the predicted dips were claimed previously by Yu. N. Parijskij of the U.S.S.R. Special Astrophysical Observatory and Steven Gull and K. J. E. Northover of Cambridge University. However, most of these results were marginal and have not been confirmed by the subsequent observations by Lake and Partridge, and Larry Rudnick of the National Radio Astronomy Observatory. The dips found recently are all associated with very distant clusters containing an extremely large number of galaxies. The detection of these dips in the cosmic background toward clusters has several important implications. It proves that the background radiation is indeed cosmic; it is shadowed by objects a billion light years away! It also shows that clusters are filled with hot, X-ray-emitting gas. Finally, it is important to note that the clusters that were detected are all at large distances (approximately 3 billion light-years) and contain a large number of member galaxies. Searches for this effect in nearby clusters (500 million light-years) containing less than half the number of galaxies have so far been unsuccessful. This suggests that the amount of gas in clusters increases rapidly with the number of galaxies and perhaps reflects the connection between the hot gas and the origin and evolution of the cluster galaxies.

These observations predict that these distant, galaxy-rich clusters

should be extremely powerful X-ray sources; their X-rays have not been detected so far because of their great distance. However, with the new generation of High Energy Astronomy Observatory X-ray satellites, they should be easily observable. The cosmic background dips and X-ray measurements give independent information on the hot gas in clusters. When combined, they should provide very useful clues to the nature of the hot gas and the origin and evolution of clusters of galaxies.

## The Internal Rotation of the Sun

It has long been known that the numbers of dark spots on the Sun's surface increase and decrease on an 11-year cycle. Astronomers believe that this sunspot cycle derives from the coupling of solar rotation with strong magnetic fields within the Sun's interior. Solar dynamo theories can account for the observed regularities of sunspot positions, magnetic polarities, and orientations



**Surface markers.** Sunspots moving across the solar disk provide a convenient means of detecting and measuring the rotation of the Sun's surface, but it had long been theorized that deeper layers of the Sun rotated at different speeds. As a result of recent research at Sacramento Peak Observatory, it is now possible to calculate those internal rotations based on observations of the visible surface.

throughout the cycle if the Sun rotates faster deep in its interior than it does at the surface. But since no light escapes from the interior, it seemed impossible until recently to determine exactly how the Sun rotates under the surface and, therefore, whether these theories are correct.

However, a new method to detect internal rotation has been devised by F. L. Duebner, a visiting scientist at the Sacramento Peak Observatory (SPO). The method uses observations made with SPO's Vacuum Tower Telescope of the oscillations of the visible surface. Until recently astronomers thought these oscillations were excited by randomly rising and falling gas bubbles near the solar surface. Three years ago, however, Duebner proved that the 5-minute oscillations represent a stable system of sound waves that are trapped in the convection zone under the visible surface. Duebner showed that the power contained in the oscillations falls into several discrete wavelength bands. Each band represents one of the fundamental modes of vibration of the convection zone, analogous to the modes of vibration of a guitar string. The location of these bands agrees very well with predictions.

During the past year Duebner found that the locations of the bands vary according to whether the waves in question travel with or against the rotation of the Sun. A small shift in wave frequency corresponds to the rotational speed of the convective layer in which the waves are trapped. Using a theory developed by Roger Ulrich of the University of California, Los Angeles, which enables one to calculate the depths at which different frequency waves are trapped, Duebner was able to determine the depth variation of rotational velocity. According to Duebner's results, the gas within the first 10,000 kilometers under the surface tends to rotate as a solid body at the surface speed. The gas in the next 5,000 kilometers,

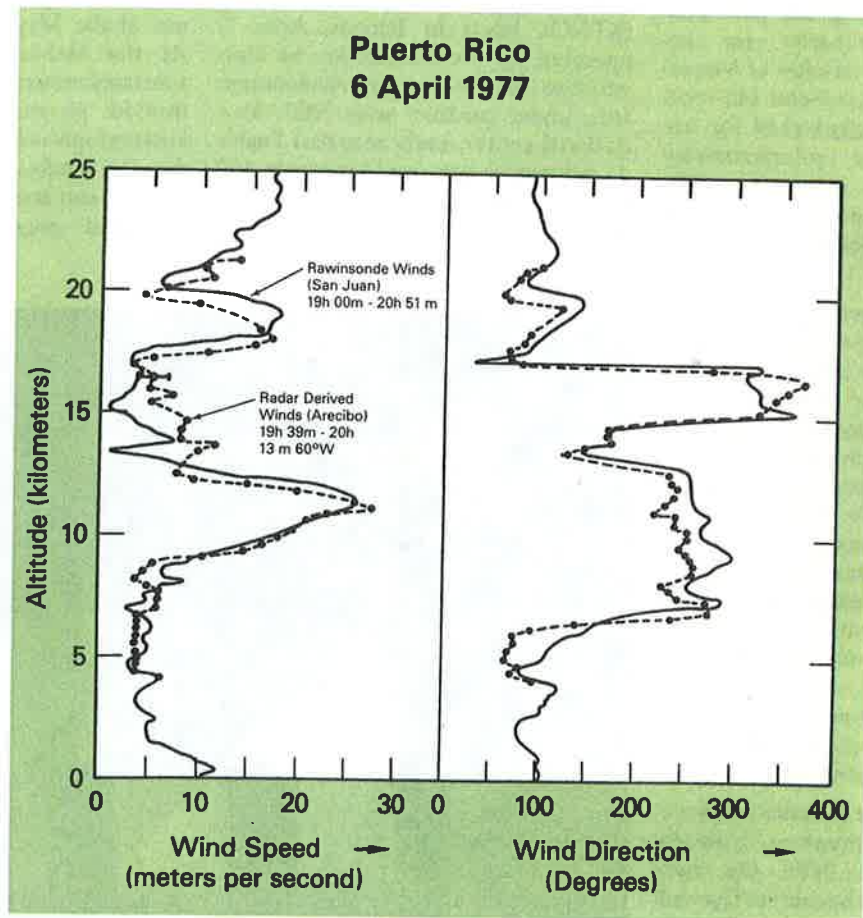
however, rotates approximately 0.1 kilometer per second more rapidly than the surface. At depths greater than 15,000 kilometers the rotational velocity decreases and eventually becomes less than the surface. This kind of behavior was quite unexpected.

The Sun is, in effect, an enormous heat engine consuming four million tons of fuel every second. Even at as great a distance as the Earth's surface, as much as five million horsepower in sunlight falls over a square mile. Duebner's theoretical breakthrough may some day lead to a better

understanding of the hidden energy source beneath the solar surface.

### National Astronomy and Ionosphere Center

The National Astronomy and Ionosphere Center (NAIC), operated by Cornell University under contract with NSF, provides the Nation with unique instrumentation and facilities required for advanced research in radio and radar astronomy and in ionospheric physics. NAIC operates the world's largest radio/radar



**Wind speeds.** Experiments with the 300-meter Arecibo dish at the National Astronomy and Ionosphere Center show that good measurements of wind speeds and directions in the upper troposphere and stratosphere can be made from the ground. The ground radar measurements (dashed lines) agreed well with direct measurements of the motion of an ascending weather balloon (solid line).

telescope, the 300-meter-diameter (1,000-foot) fixed spherical antenna located near Arecibo, P.R. NAIC's headquarters are located on the Cornell University campus in Ithaca, N.Y. The observatory and the related scientific, technical, engineering, and administrative support services conduct a wide range of different observational programs, available without charge on an equal and competitive basis to visiting scientists throughout the world.

A 30-meter-diameter (100-foot) steerable antenna, located 10 kilometers north of the main telescope in Puerto Rico, was successfully put into operation during the past year and is used primarily for interferometric radar studies of Venus. Also, a portable 12.6-meter (42-foot) antenna is being refurbished for use on an east-west interferometry baseline with the main dish. This antenna will be located at Ramey, approximately 40 kilometers west of the main site.

Among major instrumentation improvements during the past year was the implementation of a sophisticated radio spectral-line system at the observatory. This system utilizes the new and extremely flexible 1,008-channel digital autocorrelator and the new Harris 6024/6 data acquisition computer. The spectral-line system can be used with any receiver at any frequency and is designed for ease of visitor use and efficiency of operation. It features a completely interactive computer/scientist operation which allows scientists to monitor the quality of their incoming data both instantaneously and continuously.

Upgrading of the Arecibo telescope, a major ongoing program, is nearly complete. During 1978 the final alignment of the reflector surface will be completed. Even though the surface alignment is not finished, the improvement has already been so significant that the observatory has received a large number of high

quality research proposals for programs not previously possible.

Over the past year 108 different research programs were active on the telescope (compared with 67 during the previous year). These programs involved all the NAIC staff as well as 101 visiting scientists (compared with 64) from 43 different institutions (compared with 30). Of the total observing time available, 60 percent was allotted to visiting scientists.

### Kitt Peak National Observatory

Kitt Peak National Observatory (KPNO), based in Tucson, Ariz., is operated by the Association of Universities for Research in Astronomy, Inc., under contract with NSF. As a national center, each year Kitt Peak's 11 telescopes are used by nearly 300 scientists from throughout the world. Most of these visiting astronomers do

not have access to comparable equipment at their home institutions. At least 60 percent of the observing time on each telescope is allocated to visitors; research topics range from the Earth's upper atmosphere to the most distant galaxies and quasars known. Telescope time, always at a premium, is allocated on the basis of the scientific merit of the written proposals.

The observatory's resident staff of astronomers and engineers is responsible for developing instruments that are in greatest demand for modern astronomy. In the fall of 1977 a new video camera for direct imaging of very faint objects was put into regular use at the Mayall 4-meter telescope. At the McMath solar telescope, a spectroplanetograph has begun operation for planetary astronomy, and a kinetograph will soon be available for detailed studies of the solar surface, planets, and stars.

Several ongoing programs con-



**Solar telescopes.** Two of the instruments at Kitt Peak National Observatory are devoted primarily to solar research. The triangular McMath telescope is the largest solar telescope in the world; the vacuum solar telescope in the rear has a vertical vacuum tank that isolates the light beam from disturbance by local air currents.



tinually apply new techniques as they become available to astronomy. The panoramic detector program develops the hardware and software required to use two-dimensional light detectors manufactured commercially. The infrared program has a similar function in preparing new infrared detectors for use at the telescope. In the gratings laboratory, innovative techniques are used to "rule" extremely efficient diffraction gratings for the spectrographs at Kitt Peak and other observatories.

KPNO has begun investigating several concepts for a "New-Generation Telescope." The initial stage of a design study for a ground-based optical telescope of the largest feasible size is under way. The designs will take into account the most recent technological developments in optics, materials, and computers. The New-Generation Telescope, envisioned to have a 25-meter aperture, would be of unique value in studying objects much

fainter than have hitherto been observable.

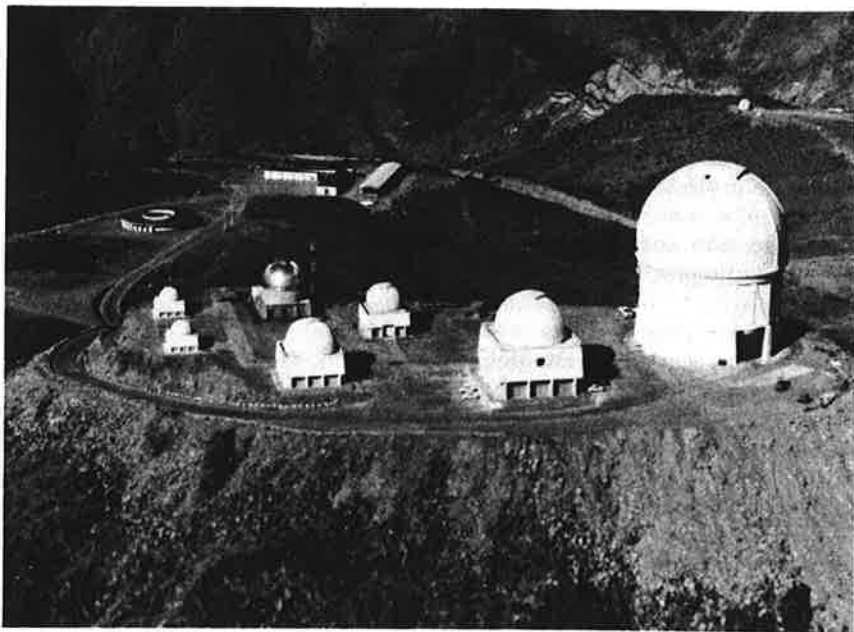
### Cerro Tololo Inter-American Observatory

Cerro Tololo Inter-American Observatory (CTIO), in the foothills of the Chilean Andes, is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the NSF. The observing facilities on Cerro Tololo, a 2,200-meter (7,200-foot) mountain approximately 80 kilometers (50 miles) inland from the coastal city of La Serena, are located at a southern latitude of 31°. Together with the Kitt Peak National Observatory (KPNO) at 32° north, the two observatories provide full-sky coverage for astronomical research. The CTIO headquarters complex in La Serena includes a computer center, engineering and technical facilities, a library, and staff housing.

The observatory's eight stellar telescopes include the Southern Hemisphere's largest, the recently completed 4-meter twin to the KPNO Mayall Telescope. The importance of this instrument to astronomical research is greatly enhanced by the excellence of observing conditions on Cerro Tololo at optical and infrared wavelengths. These result from a most fortunate set of geographical factors which give near-ideal atmospheric conditions on the mountain most of the time. Prevailing winds blowing across the cold Humboldt current off the coast of Chile form a permanent lower level inversion layer. Cerro Tololo rises above this layer to project into the clear, dry, and stable air mass above.

These conditions, together with the dark sky of the remote site, allow for effective viewing of such important Southern Hemisphere objects as the southern Milky Way, the Magellanic Clouds, and the brightest globular clusters—compact groups of hundreds of thousands of stars which are fossil-like remnants of the creation of our galaxy. At least 60 percent of the available observing time on the telescopes is assigned to visiting astronomers, the majority of whom travel to CTIO from the United States. The remaining time is used by the CTIO scientific staff. During fiscal year 1977, 129 astronomers, including 14 graduate students, from 45 U.S. and 18 foreign institutions carried out observational programs at CTIO.

During the past year CTIO completed construction of an annex in La Serena to provide office space with laboratory facilities for the Engineering and Technical Services Division. Needed space was also provided for library archives and photographic plate storage. Also during the year, an adequate supply of pure water was assured on Cerro Tololo by the completion of a new supply system drawing on a deep well about 6 kilometers (4 miles) down the moun-



**Prime observing site.** Cerro Tololo Inter-American Observatory in Chile, with its extremely clear night sky, is proving to be a superb location for optical astronomy. Cerro Tololo has eight stellar telescopes, including the Southern Hemisphere's largest, a twin to the 4-meter telescope at Kitt Peak National Observatory.

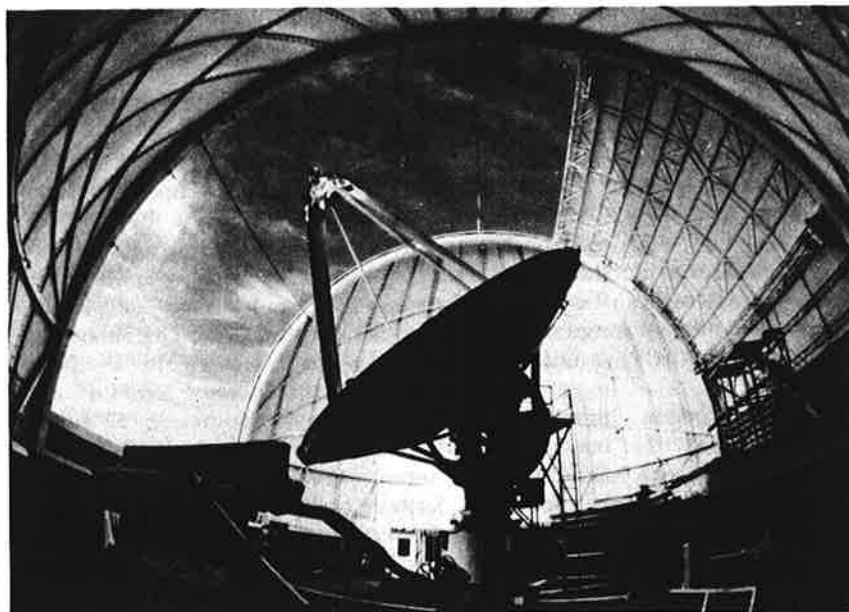
tain at 900 meters (3,000 feet) elevation.

### National Radio Astronomy Observatory

In the past year limited operation of the Very Large Array (VLA) in New Mexico began with a partially completed portion. Installation of an array of nine 24.6-meter-diameter (82-foot) antennas was completed in fiscal year 1977 along with 5.2 kilometers of railroad trackage as a base line. Agreement was reached with the vendor covering the fabrication of the remaining antennas, which will total 27 when the VLA is completed. Materials and equipment for all these antennas are on hand, and fabrication is proceeding on schedule. The new antennas are being outfitted with electronics, feeds, and cryogenic components as the antennas are received.

Three new front-end receivers have been added to the list of available receivers at other National Radio Astronomy Observatory (NRAO) telescopes. One, a Jet Propulsion Laboratory 18-26.5 GHz (gigahertz) maser amplifier, was ready for initial telescope tests in August 1977. The second receiver, also for use at Green Bank, W. Va., is a 6,035-MHz (megahertz) single-channel parametric amplifier system. The third, a 130-170 GHz temperature mixer receiver, has been developed for the 10.8-meter (36-foot) telescope at Tucson; it became available for observations in December 1977. Development of these receivers is part of a continuing program to extract more information from the very faint and complex radio signals from distant stars and gases. These signals are so weak that internal radio noise found in ordinary receivers would itself easily swamp the input signal, making radio astronomy impossible. The new low-noise maser amplifiers represent the most advanced state of the art in receiver design.

The control system for the 42-



**Interstellar organics.** The National Radio Astronomy Observatory's 36-foot millimeter-wave telescope at Kitt Peak, a key instrument in the discoveries of organic molecules in space, will be an even more effective tool as a result of equipment upgrading during the past year.

meter (140-foot) telescope at Green Bank has been improved by replacement of the Honeywell DDP 116 computer by a Modcomp II/25. In contrast to the Honeywell, this unit performs all receiver control functions and collects and passes data to the Modcomp II/25 off-line data processing system. The new control system enables the telescope operator to define and automate fairly complex control procedures.

Significant improvements have also been made in the 10.8-meter (36-foot) millimeter-wave telescope, the rotating astrodome, and other facilities at the NRAO facility on Kitt Peak. In August 1976 an electronics laboratory was completed adjacent to the telescope. A second diesel-powered generator has been installed to provide an additional source of emergency power, and a disturbance monitor is now used to record and analyze all power outages. A variable-speed dome drive and new telescope tracker now provide smoother, faster,

and more accurate dome positioning. A separate air conditioning unit has also been installed to improve the temperature regulation of the computer and filter banks. In February 1977 the telescope backup structure was modified to alleviate temperature-dependent astigmatism of the primary reflector. Subsequent tests have shown that the telescope amplification is now independent of the ambient temperature.

Last year 282 visitor scientists, representing 88 institutions, used the NRAO telescopes. Requests for observing time continued to exceed availability by a wide margin, particularly on the 10.8-meter (36-foot) millimeter-wave telescope.

### Sacramento Peak Observatory

Sacramento Peak Observatory (SPO), operated under contract with NSF by the Association of Universities for Research in Astronomy, Inc., offers unique instruments and

facilities for advanced research in solar physics and related disciplines. The SPO facilities are located at an elevation of 2,760 meters (9,200 feet) in the Sacramento mountains of south-central New Mexico. The facilities are available to all qualified scientists; telescope time is allotted on the basis of scientific proposals, which are reviewed by external referees. Approximately half of the available time is allocated to nonstaff members.

Following the recommendations of the NSF's Special Committee on SPO, the observatory has taken several steps to expand its visitor program. A summary of SPO's visitor policy has been distributed to a large number of individuals and institutions. Manuals to assist visiting scientists in the use of the telescopes and the observing equipment are now in preparation, and more housing has been set aside for visitor use.

During the past year, SPO has begun to install linear and area solid state detectors on several telescopes at the observatory. These detectors will offer visitors greatly expanded capacity for spectroscopic and photometric observations, particularly of solar phenomena, such as flares, that vary rapidly through time. The full potential of such detectors cannot be realized, however, without developing suitable image processing equipment and data compression techniques. A study group at the observatory, formed this year, has identified possible arrangements and is considering specific designs.

Because the Sun is so much closer than any other star, it is possible to observe and study numerous solar phenomena occurring at various times and in various regions of the solar atmosphere. Solar astronomers throughout the world, therefore, specialize in various observing techniques to study different phenomena. An occasional integration of these observing results with theoretical interpretation can stimulate great advances in the field. As a national

center, SPO has a responsibility to foster the necessary interactions among theorists and observers. During the past year SPO held a conference on the construction of astronomical images that are degraded by atmospheric turbulence. In September another conference was held to review the status of the large-scale solar motions—global oscillations, large-scale convection, and solar rotation.

### Radio Spectrum Management

With worldwide growth of radio telecommunications, there has been relentless pressure by users of the radio spectrum to accommodate an ever wider range of activities and services. To prevent interference among scientists and other users, transmitting frequencies must be carefully assigned and stringently regulated. The situation has become

particularly acute with the advent of large communications satellites and broadcast satellites. The Foundation, recognizing the importance of the continued availability of portions of the radio frequency spectrum for the proper conduct and advancement of many fields of scientific research, actively participates in the frequency management process. This is done through direct representation in the Interdepartment Radio Advisory Committee and support of the Committee on Radio Frequencies of the National Academy of Sciences/National Research Council. During the past year major emphasis has been placed on preparatory work for the upcoming World Administrative Radio Conference. The regulations and radio band allocations established at this conference, to be in force until the end of the century, will be of prime importance to the research use of the spectrum.

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## Atmospheric Sciences

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The Foundation's research programs in atmospheric sciences have as their goal increased understanding of the behavior of the atmosphere (from the Earth's surface to the outer reaches of space) as well as new basic knowledge required for programs to be carried out by mission agencies. Because much of the atmospheric science research in the United States is carried out by several mission agencies, the Foundation has a special responsibility to complement that work with strong NSF programs in those areas not emphasized by the mission agencies.

Atmospheric science is a derived discipline in which basic knowledge from physics, chemistry, mathematics, and biology is applied in various ways to improve our understanding of the atmosphere. As the science has

developed, it has become apparent that there are mutual interests with other sciences such as astronomy, oceanography, and geology.

Among its major topics of study are natural cycles of major gases, particles and trace molecules in both the lower and upper atmosphere, motions and radiative transfer in the troposphere, details of energy flow from the Sun, structure of the upper atmosphere and magnetosphere, and large-scale atmospheric behavior as a basis for prediction of future states of the atmosphere.

In those areas, NSF supports research by individuals (mostly in universities), operation of research facilities, field experiments, and laboratory, analytical, and numerical studies at the National Center for Atmospheric Research (NCAR).

NCAR also provides a focus for major research efforts in which its large staff and physical resources are used jointly with the university scientific community.

Other agencies of the Government, pursuing their missions to predict the weather, to characterize radio propagation processes within the ionosphere, and to observe and regulate pollution of the lower atmosphere, also conduct basic research programs in specific areas. Nevertheless, among all the agencies concerned with atmospheric science, NSF is unique in having a congressional mandate to advance basic science, to provide a foundation on which mission agencies can build both now and in the future. In line with that role, NSF's atmospheric sciences programs provide over half of the support for basic research in atmospheric sciences conducted by the Nation's universities.

The Foundation's four basic atmospheric science programs are solar terrestrial physics, aeronomy, atmospheric chemistry, and meteorology. Two other programs—the Global Atmospheric Research Program and climate dynamics—are multidisciplinary, involving interagency and international cooperation. All of the programs support research through grants to individual investigators. NCAR, with headquarters and facilities in Boulder, Colo., supports a broad spectrum of research. In addition, it provides facilities, such as a major computer, aircraft, balloon launch, radar operation, and instrument development facilities, that are too large or expensive for an individual institution to maintain.

### **Project GAMETAG: Chemistry of the Troposphere**

Representing a cooperative effort between meteorologists, cloud physicists, and atmospheric chemists,

a 2-year project called GAMETAG (Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases) was begun in 1977 to enhance understanding of the chemistry of the natural as well as of the perturbed troposphere (which extends from the Earth's surface to the bottom of the stratosphere). To achieve this, scientists from the National Center for Atmospheric Research and from universities and private industry have planned a major atmospheric measurements program. This program recognizes the importance of chemically coupled atmospheric species and of coupled chemistry and meteorology. Data collection during GAMETAG experiments will emphasize simultaneous measurements on over 50 different atmospheric species and meteorological parameters.

Using NCAR's Electra aircraft as a sampling platform, with the university effort being headed by Douglas Davis of the Georgia Institute of Technology, two major GAMETAG flight operations per year are scheduled. These flights span a global latitude range from 75° N. to 55° S. and a longitude range from 165° to 30°. The general sampling plan for GAMETAG operations includes transit flights into polar, tropical, and transition air masses that have been modified both by continents and oceans and by large-scale ascent and descent.

Although detailed processing of the voluminous amounts of data collected during the first flight operation (August to September 1977) has just begun, several instruments giving real-time readouts during the summer 1977 flight program did reveal important major findings in the South Pacific. The global sulfur cycle is one of the most important chemical cycles in nature and has significance in providing a basis for estimating the effects of manmade pollution. Both carbonyl sulfide (COS) and sulfur

dioxide (SO<sub>2</sub>) were measured for the first time over large stretches of the Pacific Ocean. A tentative conclusion from the SO<sub>2</sub> data is that the tropical ocean waters are, in fact, a source of gaseous sulfur species (i.e., H<sub>2</sub>S, (CH<sub>3</sub>)<sub>2</sub>S, or SO<sub>2</sub>). This is in sharp contrast to previous conjectures of scientists.

The single nitrogen species for which real-time data were available was nitric oxide. These measurements over tropical Pacific waters were the first ever made, and for middle tropospheric altitudes, above the marine boundary, typical levels of nitric oxide were found to be 100 parts per trillion. These levels are far lower than those being used in most tropospheric chemical models, and it now seems likely that the dominant reaction mechanism used in these models will have to be significantly altered.

Certainly one of the major discoveries of the South Pacific GAMETAG flight was the observation that marine boundary layer air and middle tropospheric air over large regions of the Pacific Ocean differ enormously in their ozone levels. Marine boundary layer air over the latitude range of 37° N. to 25° S. typically contained very low average levels of ozone, 20 parts per billion (ppb), with lows of 10 and highs of 25 ppb. In sharp contrast to this, above the boundary layer and up to 6,400 meters, the average ozone levels were 40 ppb. Superimposed on these higher average levels of ozone were intense bands (typically 300 to 600 meters in thickness) with maximum concentrations of ozone reaching 90 to 100 ppb. These tropospheric Pacific ozone (TPO) bands were observed over the entire Pacific Ocean. Only within the inter-tropical convergence zone near the Equator, between 13° N. and 17° S. latitude, was there a marked decrease in the average level of ozone above the boundary layer and in the number and intensity of the TPO bands. The





**Flying laboratory.** Simultaneous measurements of atmospheric chemistry and weather for Project GAMETAG are made with the National Center for Atmospheric Research's Electra aircraft. The 2-year global study is providing needed information on chemical conditions in the lower atmosphere.

importance of TPO bands will undoubtedly be the subject of considerable future scientific debate, because the assumption has been that ozone was fairly well mixed throughout the troposphere.

In studies of chlorinated compounds, a major finding was the variation with altitude of the observed amounts of methylchloroform. Two unique situations presented themselves: (1) There was a significant depletion of methylchloroform in the marine boundary layer compared to the region directly above; and (2) In the region above the boundary layer there was a measurable decrease in the concentration of methylchloroform in samples from within an intense tropospheric ozone band compared to samples taken outside the same TPO band.

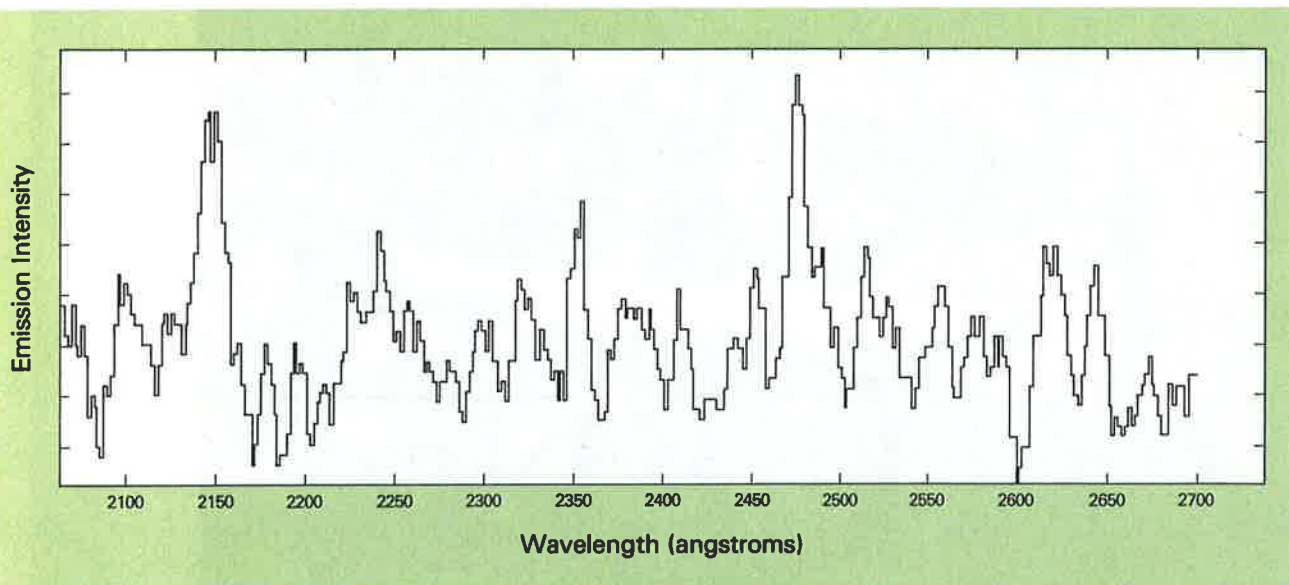
The hydroxyl radical (OH), although present in tiny concentrations in the troposphere, plays a

role in many important chemical reactions in the atmosphere. GAMETAG measurements of OH concentrations over several thousands of kilometers of tropical Pacific Ocean were the first of their kind, and the data will form the basis for the most significant test yet made of present atmospheric chemical models. Very preliminary data processing has shown that great care will have to be taken in future modeling of OH-induced chemistry. For example, over tropical Pacific waters, moderate to high levels of OH were observed in the marine boundary; however, directly above the boundary layer, low to very low levels were found due to the low water content of the air. The one exception was over the inter-tropical convergence zone where moderate levels of OH were observed, even at high altitudes, due to the strong mixing there, with subsequently higher water content.

### Nitrogen in the Upper Atmosphere

Nitric oxide ( $\text{NO}_x$ ) and its ion,  $\text{NO}^+$ , play pivotal roles in the physics and chemistry of our atmosphere. For example, at stratospheric altitudes, NO behaves as a catalyst, regulating the Earth's protective ozone layer. Above 60 kilometers, in the mesosphere, the photoionization of NO is the principal source of the D-region ionosphere.  $\text{NO}^+$  ions are equally important in the atmosphere because they stabilize the entire ionosphere through disassociative recombination.

The need to understand the chemical and physical properties of NO,  $\text{NO}^+$ , and the related  $\text{NO}_x$  compounds has stimulated a variety of laboratory and field studies. These experiments have yielded some significant geophysical insights this year. For example:



**Auroral mystery feature.** The ultraviolet light emission spectrum of one type of aurora shows, in addition to the expected peaks in intensity in the middle and right of this record, a sharp peak at 2,150 angstroms. Scientists believe this to be an emission produced by excited NO molecules, but laboratory tests have not been able to confirm the mechanism.

- A renewed interest in  $\text{NO}_x$  production by lightning indicates that this may produce nearly 60 million metric tons of  $\text{NO}_x$  compounds annually. If that is the case, then thunderstorms account for more than half of the  $\text{NO}_x$  molecules of atmospheric origin and so provide part of the natural fertilization mechanism for vegetation.
- There is growing evidence that shock waves associated with the more than 200 million meteors that enter our atmosphere each day are a significant (perhaps even dominant) source of NO in the mesosphere.
- In the upper atmosphere, the formation of nitric oxide is a consequence of the disassociation of  $\text{N}_2$  molecules by electron impact and by the absorption of extreme ultraviolet radiation from the Sun. Recent laboratory studies have resulted, for the first time, in a comprehensive and quantitative understanding of the many processes that contribute to the disassociation of  $\text{N}_2$  in the upper atmosphere. These insights also contribute to a better understanding of a wide variety of gas discharge phenomena involving  $\text{N}_2$  that have potential commercial value.
- Further data have been obtained on so-called nitric oxide aurora. These are magnetospheric substorms in which there are local enhancements of the NO concentration by two or three orders of magnitude restricted spatially to narrow tubes, perhaps 1 to 10 kilometers in diameter, aligned along the magnetic field lines. Conventional ion chemistry is completely incapable of explaining this phenomenon, which appears (in unknown ways) to be associated with anomalous electric fields and vibrationally excited  $\text{N}_2$ .
- Progress has also been made on the study of the so-called auroral mystery feature, an unusual light emitted at a wavelength of 2,150 angstroms in some, but not all substorms. It is believed that this radiation is produced by excited NO molecules, but very detailed laboratory studies have failed to duplicate the observed auroral spectrum by exciting the gases found in the normal atmosphere. It is now hypothesized that this remarkable emission feature is produced by ion-molecule reactions involving polyatomic species such as  $\text{N}_2\text{O}^+$  and  $\text{NO}_2^+$ .

### Airglow and Aurora

Recently, several teams have succeeded for the first time in observing the extreme ultraviolet spec-

trum of terrestrial airglow and aurora in the difficult wavelength range 500 to 1,100 angstroms. When these results are combined with detailed laboratory cross section measurements of the nearly 200 emission features that contribute to the Earth's extreme ultraviolet (EUV) spectrum, two remarkable new insights emerge:

- There appears to be a 16-percent error in our calculations of the overall energy budget of a magnetospheric substorm (aurora). Inasmuch as the energy deposited worldwide by these storms is at a rate of 1 trillion watts or more, the discrepancy amounts to a staggering 160 million watts.
- Radiation entrapment affects control of much of what ultimately happens to the EUV photons created in the upper atmosphere. As our observational data base improves, the need for more realistic entrapment calculations becomes apparent. The problem is very difficult because the presence of transient species such as vibrationally excited nitrogen molecules in some auroras has been shown to dramatically modify the apparent EUV spectrum.

The role of vibrationally excited molecules and ions in planetary atmospheres also arises in an entirely different context, namely, the question of the identity and origin of the strange 1,400-angstrom emission feature that appears in the vacuum ultraviolet spectrum (VUV) of Venus. This emission is not observed in the VUV spectrum of Mars, which also has a CO<sub>2</sub>-based atmosphere. The explanation for this remarkable radiation was discovered in a laboratory plasma physics experiment, which showed that the light was produced by the disassociative recombination of vibrationally excited CO<sub>2</sub><sup>+</sup> ions.

It is not known how the Venus ionosphere, but not that of Mars, creates significant quantities of vibrationally excited ions, but it may involve the presence of weak electric fields. In fact, an entirely different complement of experiments has only recently led to the same conclusions for the Earth's upper atmosphere. Study and careful modeling of a comprehensive set of observations of upper atmospheric optical emissions and ionic composition has shown that the role of excited states plays an important, and in some cases, dominant role in upper atmospheric behavior.

### Surface Wind Observation

Michael Garstang of the University of Virginia has recently shown how surface observations of winds may be used to predict the onset of showers in Florida. As air flows over the Earth's surface, currents frequently converge, causing some of the air to ascend. As we know, the ascent of warm moist air frequently leads to the formation of clouds and rain. But what is surprising is the observed lag between the convergence at the surface and the onset of showers. Indeed, when the winds were examined from a special observational network, the convergence of the air preceded the rainfall by about 1 hour. This correlation offers encouragement that these results can be used for the short-range prediction of rain showers in Florida.

### Climate Dynamics

#### Recognition of Solar and Planetary Cycles in the Climatic Data

Solar and planetary cycles in climatic data figure prominently in the past year's results from research supported by NSF's climate dynamics program. Paul Schickedanz of the Illinois State Water Survey and E. G.

Bowen, a private consultant to the Survey, have developed a statistical technique for time series analyses of short-term temperature and precipitation data. Application of this method to rainfall data for the Southwestern United States shows a repeated cycle every 21 to 22 years. Similarly, Charles Stockton of the University of Arizona's Laboratory of Tree-Ring Research has reconstructed, from tree ring thicknesses, a drought index for a large part of the Western United States for the period 1700 to 1962. Time series analysis of the tree-ring data shows that a major drought occurs approximately every 20 years. Thus the 20- to 22-year cycle found in the precipitation and tree-ring data is very close to the double sunspot cycle of 22 years. Times of maximum drought lag behind times of minimum sunspot activity by approximately 2 years. Scientists are investigating possible relationships between the sunspot cycle and meteorological variables such as temperatures and precipitation cycles.

Over longer time periods, evidence compiled by James Hays of Lamont-Doherty Geological Observatory, John Imbrie of Brown University, and Nicholas Shackleton of Cambridge University from deep sea cores indicate that over the past 500,000 years the cycles of climate change on the Earth correspond to the dominant periods of variations in the Earth's orbit (100,000, 41,000, 23,000, and 19,000 years). The climate pattern deduced from deep sea records older than 500,000 years is quite different. Research on this subject will be expanded during the coming year.

Finally, as an update on climate trends over the past 50 years, George Kukla of Lamont-Doherty as well as other academic and government scientists have shown that the oscillatory cooling observed over the past three decades is continuing. Concurrent with this general cooling is the continued increase in global snow cover, which is also indicative of

continued cooling in that the snow cover reflects the incoming solar radiation, thus making the surrounding air cooler.

## Global Atmospheric Research Program

### GARP Atlantic Tropical Experiment (GATE) Workshop

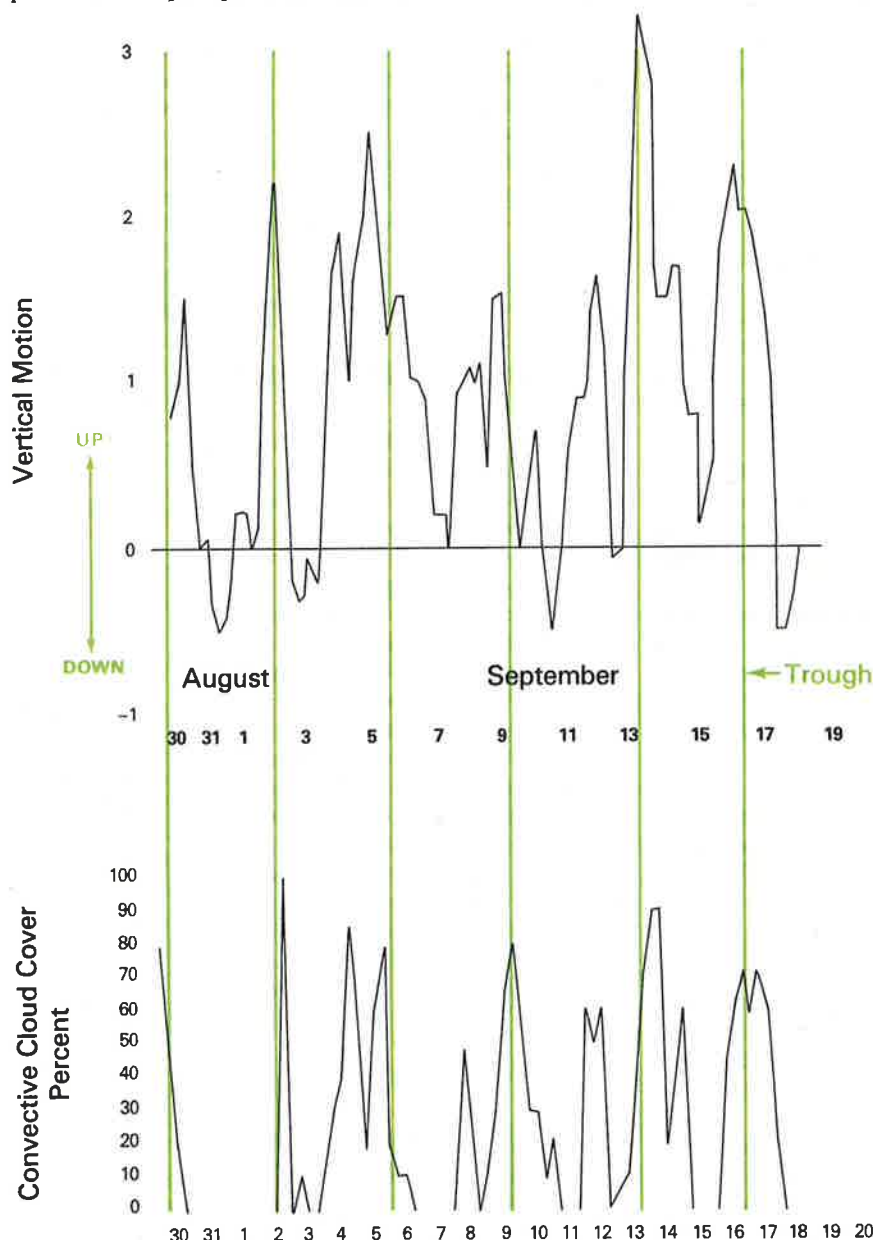
The largest field experiment ever conducted in atmospheric science was the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE), held in 1974. The primary GATE objectives were to estimate the effects of small-scale tropical weather systems on the large-scale air motions and to improve numerical tropical weather prediction by accounting for those effects in numerical prediction models. The observational phase of GATE was conducted from July to September 1974 and involved approximately 5,000 people from 72 nations using 6 satellites, 39 ships, 13 aircraft, and 1,000 land stations.

From July 25 to August 12, 1977, some 150 scientists met at the National Center for Atmospheric Research (NCAR) in a workshop, jointly sponsored by NSF and the National Oceanic and Atmospheric Administration, to summarize the knowledge obtained thus far using GATE data, to assess the progress by the United States in achieving the GATE objectives, and to recommend promising research that should be pursued in the future.

The general conclusions of the workshops are that a great deal has been accomplished in organizing and analyzing the GATE data. There are some significant limitations in the data, and alternatives were suggested to fill resultant gaps; e.g., using satellite, radar, or aircraft data to make up for deficiencies in the data obtained from balloon-borne electronic sounding systems.

One highly significant scientific result, widely discussed at the workshop, was the demonstration of the close relationship between patterns of precipitation and the

large-scale waves in the easterly winds over the Eastern Atlantic and Africa. Similar relationships were noted between the "easterly wave" and large cloud patterns. These



**Easterly waves and precipitation.** Measurements made during the GARP Atlantic Tropical Experiment over the eastern Atlantic and Africa show a strong correlation between three events: upward vertical air motion; convective cloud cover; and, what is probably the causative factor, the passage of "troughs" of large, easterly waves about  $3\frac{1}{2}$  days apart. Better knowledge of these relationships could have important benefits in weather prediction. (After R. M. Thompson, E. E. Recker, and R. T. Reed/University of Washington)

results tend to confirm the hypothesis that there is a relationship between the large-scale ("easterly waves") and smaller scale (precipitation and cloud patterns) tropical phenomena—one of the main hypotheses being tested by GATE. If these relationships can be accurately quantified, numerical weather prediction may be dramatically improved. A detailed report of the workshop findings will be published.

### The Energy Source of the Midlatitude Jet Stream

For several decades, meteorologists have viewed large-scale weather systems as the energy source of the midlatitude jet streams that circumscribe the globe at altitudes of about 10 kilometers. However, recent results of a cooperative research program between J. M. Wallace, N. Lau, and S. Mullen of the University of Washington and M. Blackmon of the National Center for Atmospheric Research (NCAR) throw open to question the currently accepted theories about the source of energy of the midlatitude jet stream. Their analysis of data from nine winters shows that these large-scale systems actually serve as a brake on the jet stream. The energy source for the jets appears to come from circulations produced directly from solar heating differences between low and high latitudes; that is, a flow of air from the colder regions of northern latitudes to the warmer regions of the tropical latitudes. This observational result is quite important because it radically changes our understanding of jet streams and their relationship to weather systems and short-term climatic variability.

### National Center for Atmospheric Research

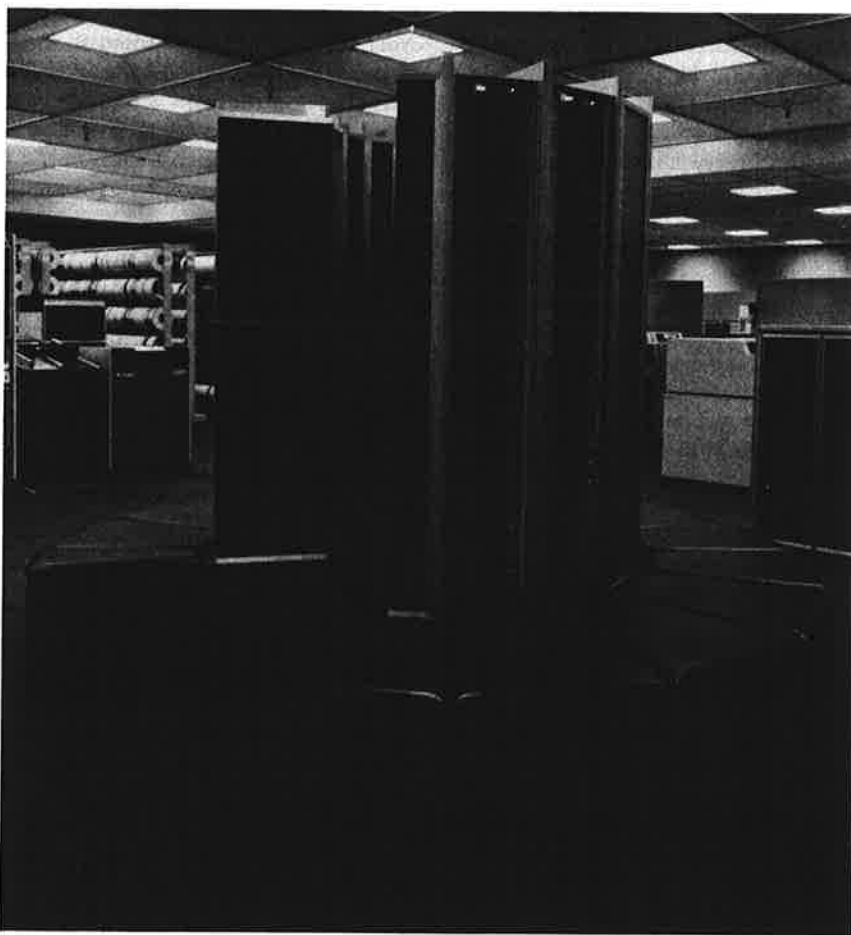
The National Center for Atmospheric Research (NCAR) carries out major atmospheric research programs

of national and international scope in cooperation with universities and other institutions. NCAR also maintains and develops major research facilities that are made available to the atmospheric science community. The Center is operated by the University Corporation for Atmospheric Research, a nonprofit consortium of 43 U.S. and two Canadian universities, under contract with NSF.

NCAR is a participant in several aspects of the Global Atmospheric Research Program (GARP), including

management of the aircraft data collected during the GARP Atlantic Tropical Experiment (GATE) in 1974 and coordination of U.S. participation in the GARP Monsoon Experiment (MONEX), to be conducted in 1979 to study the summer and winter monsoon circulations in eastern Africa and India.

The First GARP Global Experiment (FGGE), scheduled for 1978 and 1979, will be a worldwide effort to gather atmospheric data using a global array of instruments and platforms. One of its objectives is to increase the ac-



**New computer.** NCAR's fifth-generation computer is a CRAY-1, which can process 80 million instructions per second and has a memory which can contain a million 14-digit numbers. The new computer, available for use by the atmospheric sciences community, is needed for large-scale numerical weather prediction models and for processing very large amounts of data collected in field experiments.

curacy of numerical weather prediction. Reduction and analysis of the vast amounts of field data that will be gathered in FGGE will be greatly assisted by NCAR's recently acquired CRAY-1, a fifth-generation computer with a memory of one million 64-bit words augmented by 16 disks with a capacity of 40 billion bits. This computer will be available to university and NCAR scientists for a variety of numerical simulations of atmospheric events. The first programs to be run on the CRAY-1 in the fall of 1977 included NCAR's third-generation model of the global atmospheric circulation; Drexel University's mesoscale weather prediction model; a model of the circulation of the North Atlantic ocean basin; several cloud models developed at the University of Hawaii, the University of Illinois, and Colorado State University; and a model of the differential rotation of the Sun.

Other research facilities available at NCAR include a fleet of five instrumented aircraft. In the past year scientists in NCAR's National Hail Research Experiment (NHRE) have carried out combined ground-based and aircraft studies of storm clouds and have found that many storm clouds behave in a fashion different than that envisioned in existing models of such clouds. The clouds studied contained strong updrafts that drew into themselves; i.e., entrained far less of the midlevel air around them than had been expected. The extent to which the environmental air is mixed into a storm cloud updraft region is important in controlling the cloud's development. The assumption that there is considerable lateral entrainment into most updrafts had been supported by earlier studies of smaller maritime clouds; the NHRE results indicate that the assumption may have to be revised for large, continental storm clouds. This finding has implications for the evaluation of techniques for potential weather modification.

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## Earth Sciences

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This is the decade of the restless Earth. That the fluid envelope of the planet is in constant motion has been known for a long time, and was spectacularly confirmed by satellite pictures. But until just a few years ago, *terra* was reasonably *firma*. To be sure, it quaked, and local volcanoes spewed forth lava, and mountain ranges were slowly upraised by compressive stresses (whose origin remained a mystery); but by and large we could and did count on the general permanence of the continents and ocean basins. Then about 15 years ago Harry Hess at Princeton University suggested something called "sea-floor spreading," and from this evolved the concept of plate tectonics. Now, far from being fixed, the continents move back and forth, passengers on still larger plates; and the architecture of the whole Earth is revealed by great linear belts of earthquakes that outline the contacts between these blocks or plates.

It's a compellingly simple and attractive hypothesis. It provides, for the first time in the history of geology, a model to explain the Earth as a whole and a concept that is simple enough to be grasped by most nonscientists. Stated very briefly, the plate tectonics concept holds that new crust is constantly being generated along mid-ocean ridges; hot molten material rises from the underlying mantle, cools, and is forced aside by new molten material coming from the depths. Thus, the ocean floor is in movement, the principal direction being at right angles to and away from the center of the mid-ocean ridges. Ultimately the crust moves to an area such as deep sea trenches where it is drawn down and reabsorbed into the Earth's mantle. Because the crust is not infinitely strong, it does not move as a single unit but is broken up into major

plates. Along their boundaries the plates move parallel, or move apart (as at spreading centers), or collide. As the plates move they carry not only the upper part of the oceanic crust, but the continents as well.

According to today's model, the current spreading cycle started about 200 million years ago. At that time the present continents were essentially one land mass, which split apart along what is now the Mid-Atlantic Ridge and have since been moving apart at about 2 centimeters per year. Before that, perhaps 500 million years ago, an older ancestral Atlantic may have opened and then closed with a collision that formed the Appalachian Mountains.

Plate tectonics is especially attractive because it provides a ready explanation for phenomena such as the distribution of earthquakes, volcanoes, and some ore deposits, as well as giving a model for mountain building and most tectonic processes. Most importantly, the supporting evidence comes from such diverse subfields as paleomagnetism, marine geology, seismology, gravity, paleontology, and stratigraphy.

But, like any promising new idea, plate tectonics has developed strong momentum and perhaps runs the risk of being accepted too uncritically. Much of the supporting evidence is permissive rather than conclusive, and the overall model has gaps. For example, plate tectonics does much better in explaining oceanic crust than continental crust. It does very well in explaining horizontal movements, not so well for vertical. And the overall driving force is still speculative.

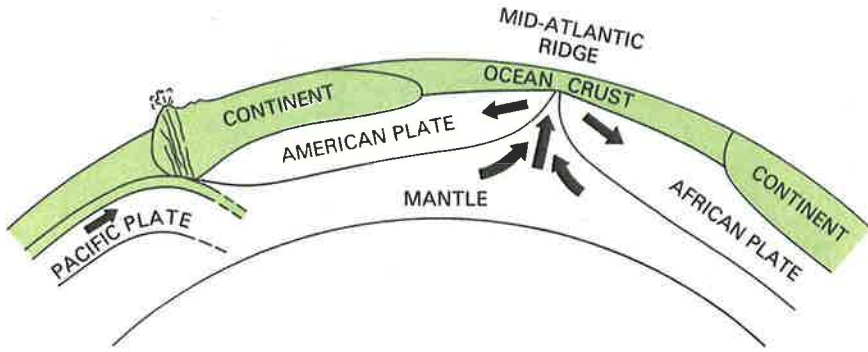
Strictly speaking, then, we do not as yet have a full-fledged hypothesis, but rather a pragmatic model, attractive and versatile, tempting and intriguing, but still in need of a lot of work, both



observational and theoretical. Even so, its importance to science can hardly be overemphasized, for it has provided a

new vehicle for moving ahead, a new framework in which to set observations and integrate the inputs in many

subfields. The testing and evaluation of plate tectonics will undoubtedly guide and dominate geologic research for the rest of the century.

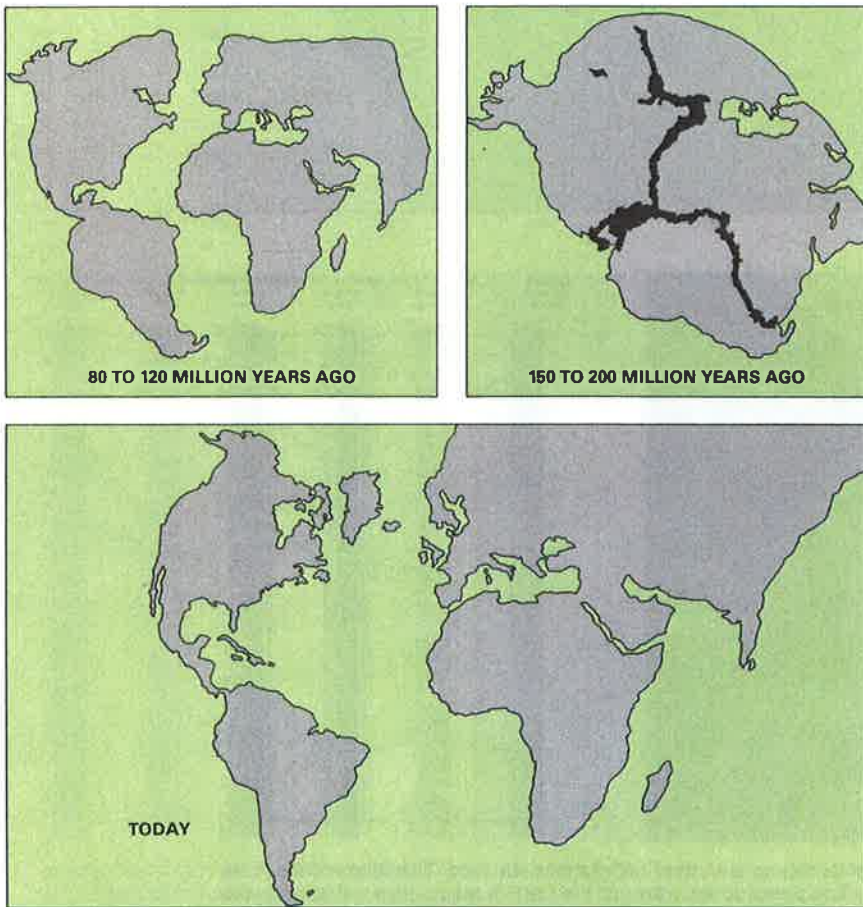


### Spreading Rates of the Ocean

We have known for some time that the Earth's magnetic field reverses episodically and that the time between reversals varies between a few thousand and a few hundred thousand years. These magnetic reversals are also recorded by the process of sea-floor spreading, because as molten lava cools at the spreading centers, it acquires the magnetic imprint of the Earth's field at that time. Then as it moves away from the center, it carries a record of that polarity with it. Thus, the ocean floor is striped with lines of normal and reversed polarity.

By correlating the ocean stripes with dated magnetic anomalies on land, we can build up a magnetic chronology for the ocean floor and determine the spreading rates. This has been done in some detail for the period covering the past few million years. Now a group of scientists from Princeton, Columbia's Lamont-Doherty Geological Observatory, and several European universities has established a standard reference section for dating reversals of the upper Cretaceous and Paleocene geologic epochs—between 65 and 100 million years ago.

The type section is at Gubbio in the Italian Apennine Mountains, where sedimentary rocks deposited in deep waters of the ancestral Mediterranean Sea were uplifted by the continental collisions that formed the alpine mountains of southern Europe. A record of the alternating polarity of the magnetic field is preserved in magnetic minerals deposited in the sedimentary strata, which also contain abundant microfossils that allow paleontological correlation of the strata with Cretaceous and Paleocene



**Plate tectonics.** The current theory of how the Earth's surface changes is that new crust is created at mid-ocean ridges, from which it spreads as part of a large plate until, eventually, it meets another plate. At that point one plunges beneath the other, accompanied by earthquakes, mountain-building, and volcanism. This theory also can account for the splitting apart and drifting of continents, which move as part of the major crustal plates.

sedimentary rocks elsewhere on land and in deep sea cores.

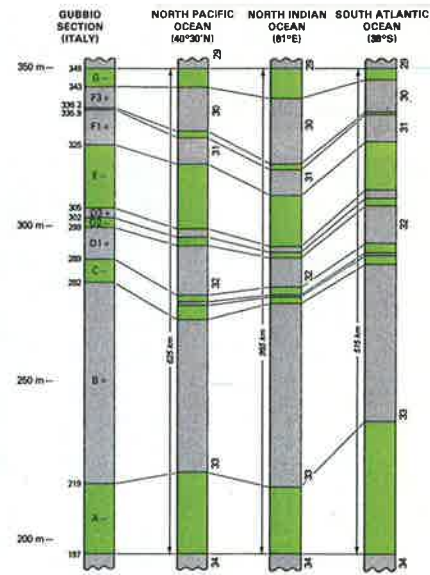
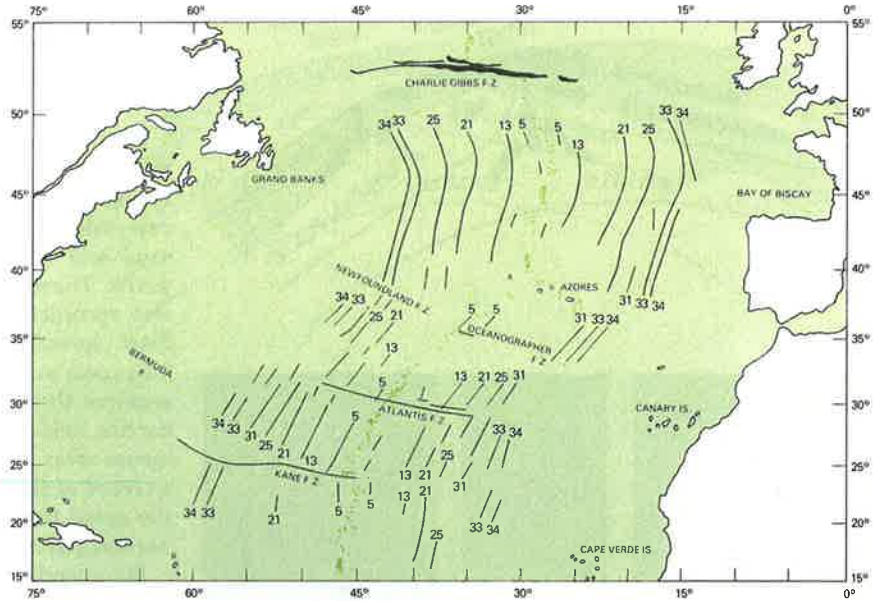
Information from the newly proposed type section at Gubbio has already been used in revising the correlation of some controversial Cretaceous anomalies in the North Atlantic Ocean and as an aid both in recalibrating the Cenozoic polarity time scale and in revising estimates of Cenozoic spreading rates.

### Fine Structure of the Crust and Upper Mantle

In the *Annual Report* for fiscal year 1975 we reported on a test project to use seismic reflection profiling for studying the deep structure of the crust and upper mantle of the Earth. This first field test in Hardeman County, Tex., showed great promise, and the project was expanded. Two other sites have since been in-

vestigated: the Rio Grande Rift near Abo Pass and at Socorro, N. Mex.; and the Wind River Uplift area in Wyom-

ing. Each of these sites is associated with an important unresolved geological problem, and the new data



**Age of the oceans.** As rocks are formed, magnetic minerals tend to line up with the Earth's magnetic field. This alignment occurs both on sedimentary deposition and as volcanic magma cools. The periodic reversals of the Earth's magnetism reflected in the rocks can therefore be used as time reference points. Recent establishment of a "type section" of sedimentary rocks of known ages in Italy (left) now permits geologists to assign geologic ages (based on fossils) to periods of magnetic reversal between 65 and 100 million years ago, far older than could be accurately done before. The pattern of magnetic reversals in this type section (right) can be matched with magnetic records obtained from measurements on the ocean floor (the matchups are unmistakable in spite of differences in accumulation rates). The numbers—29-34—in the sections (right) correspond to magnetic "stripes" on the sea floor (above) on either side of the spreading center (shown in color), thus allowing the assignment of ages to those parts of the ocean floor. Note the offsets of these stripes by prominent east-west fracture zones.

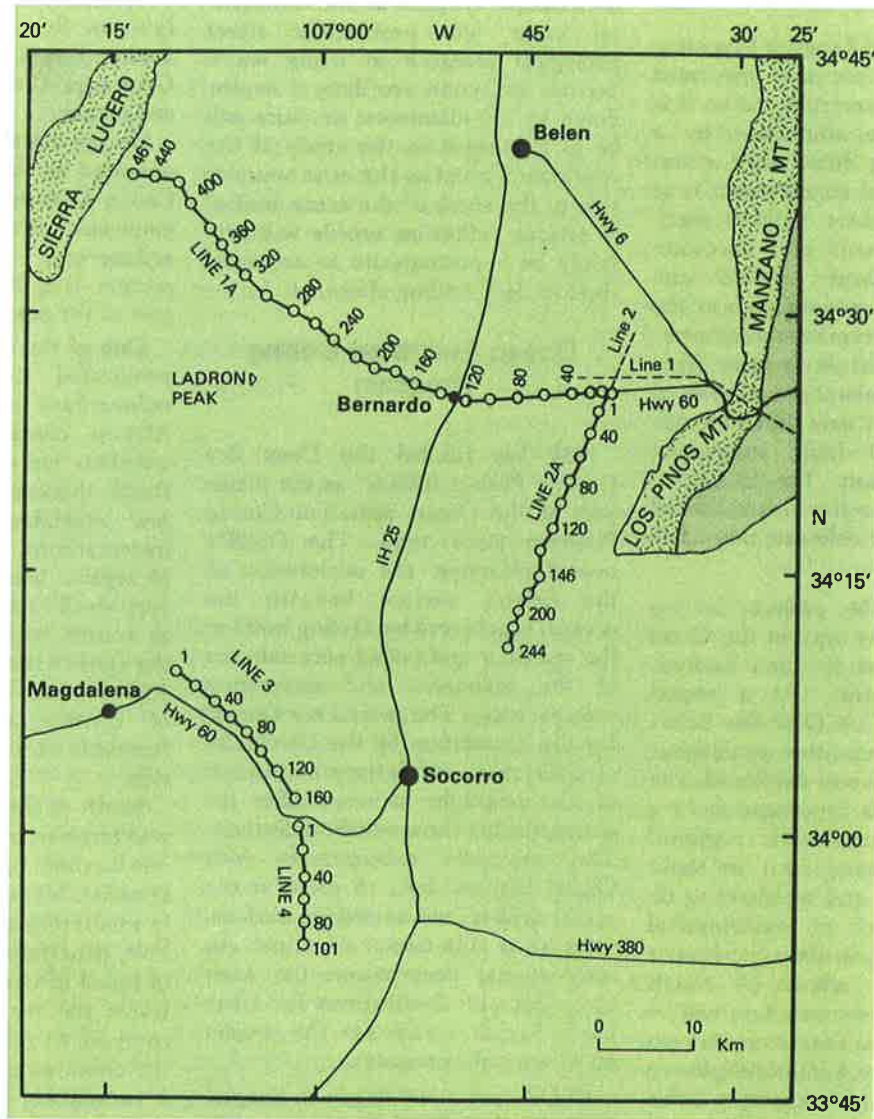
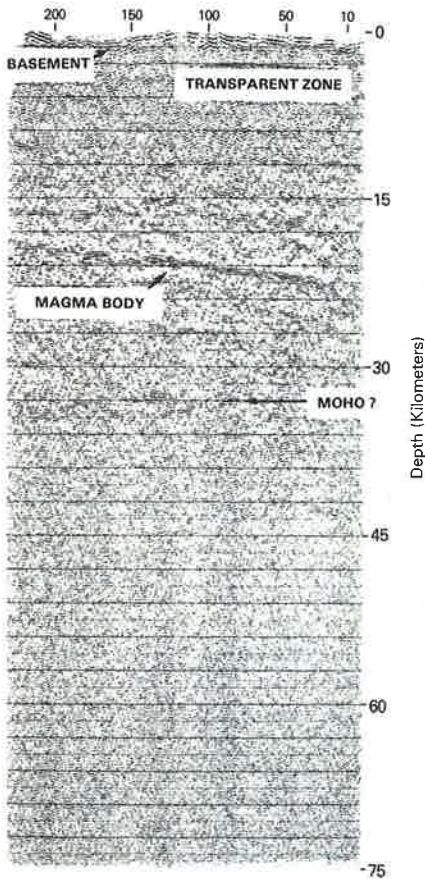


are already making a significant contribution to the solution of these problems.

The project is run by the Consortium for Continental Profiling (COCORP), which consists of five universities—Cornell, Princeton, Wisconsin, Texas at Austin, and Houston, with Cornell designated as the operating institution. The project was initiated to see whether seismic reflection techniques used by the petroleum industry could be extended and modified to study the deep structure of the crust and upper mantle. The central goal of the project is to provide new knowledge of the continental basement, a research area

that offers possible solutions to, or information on, some of the most important and fundamental problems facing earth science. These include the origins and evolution of continents, as well as background for a host of more practical questions relating to mineral deposits, energy resources (especially geothermal), and earthquake and volcano hazards.

The Abo Pass and Socorro sites in New Mexico are associated with a major structural feature in the Earth's crust—the Rio Grande Rift. This is an area of high heat flow and crustal uplift. On the basis of several microearthquake studies, A. Sanford of the New Mexico Institute of Mining and Technology has proposed the existence of a molten layer at



**Deep profile.** Recent surface investigations of the Earth's crust using a new seismic reflection technique have identified a deep layer of molten rock that had been predicted to exist in the Rio Grande Rift near Socorro, N. Mex. This record (left), taken along line 2A south of Highway 60 (right), shows the layered sediments at the surface, the crystalline basement rock below, and the top of the magma body some 21 kilometers deep. Such a magma body has potential as a geothermal energy source.

shallow depths underlying much of the area around Socorro. The seismic profiles obtained by COCORP in this area show a strong reflection from precisely the depth for the molten layer hypothesized by Sanford. Using the reflection profiling techniques employed in the COCORP project, scientists will now be able to trace the exact shape and extent of this molten layer, which could prove to be a valuable source of geothermal energy.

The Wind River Range in Wyoming is an area of intensely deformed Precambrian metamorphic rocks. It is bounded on the southwest by a northeast dipping thrust fault whose maximum vertical displacement is at least 10,500 meters (35,000 feet). Until now we could only speculate whether the large vertical and horizontal displacements seen at the surface resulted from lateral compression along the thrust fault or from vertical uplift. Preliminary analysis of the new COCORP data shows a major low-angle thrust fault, suggesting lateral compression. The COCORP project returned to this area in the fall of 1977 to further delineate this major crustal fault.

In addition, the project has investigations under way in the Great Valley and across the San Andreas Fault in California. At a recent meeting of the COCORP Site Selection Advisory Committee, a multiyear plan of field work was developed. The plan involves the investigation of a number of important regional geological problems, such as those discussed above, and attempts to tie them together in continental traverses so that, in time, a coherent picture of the whole of North American basement structure will be available. It is clear that to obtain such a coherent picture, a multidisciplinary effort—involving, for example, fields as diverse as gravity, magnetics, and electrical conductivity—will be required. The COCORP project has already stimulated a number of such

ancillary projects which are supported by NSF's earth science program.

The COCORP project has been a priority initiative of the U.S. Geodynamics Program. Because the focus of this program, after 1979, seems to be turning towards a study of the origin, structure, and history of continents, the COCORP effort will be even more important. The availability of two- and three-dimensional sections of the continental crust will profoundly affect geological research in many ways. Seismic reflection profiling at depths down to 100 kilometers or more will be as important to the study of the continental crust as the echo sounder was to the study of the ocean basins. A seismic reflection profile will certainly be a prerequisite to any continental deep drilling effort.

### Ocean Sediment Coring Program

NSF has funded the Deep Sea Drilling Project (DSDP) as the major part of the Ocean Sediment Coring Program since 1966. The DSDP's overall objective, the exploration of the Earth's surface beneath the oceans, is achieved by drilling holes in the sea floor and taking core samples of the sediments and underlying volcanic rocks. The project is managed for the Foundation by the University of California, and Scripps Institution of Oceanography is responsible for accomplishing the scientific objectives. The university subcontracts with Global Marine, Inc., to perform the actual drilling and coring operations, using their ship *Glomar Challenger*. An international consortium—the Joint Oceanographic Institutions for Deep Earth Sampling—advises the project on its scientific program.

DSDP operations began in August 1968. By the end of September 1977 *Glomar Challenger* had drilled 651 holes at 433 locations in a series of 54 2-month cruises (legs) covering all the

major ocean basins except the Arctic. From the beginning, the world scientific community has shown great interest in the project, and many scientists from outside the United States have made significant contributions, either as participants aboard *Glomar Challenger* or as members of the advisory panels. The current International Phase of Ocean Drilling, which began in October 1975, now receives \$1 million annually from five foreign countries (the Soviet Union, Federal Republic of Germany, United Kingdom, France, and Japan).

During fiscal year 1977, *Challenger* operated in both the Atlantic and Pacific Oceans. In the Atlantic the emphasis was on deep drilling into the sedimentary rocks of the ocean margin (Leg 50) and into the older part of the oceanic crust (Legs 51-53).

One of the holes drilled on Leg 50 penetrated 1,624 meters into the sedimentary record off the northwest African continental margin. Here scientists were able to document the steady maturing of plant debris from raw vegetable matter into mature hydrocarbons. The actual quantities of organic matter in the rocks were very small—too small to qualify them as source rocks for petroleum—but the mature state of the material below 1,200 meters suggests that other parts of continental margins may be favorable sites for petroleum exploration.

South of the Bermuda Rise drilling was targeted on much older crust. At one location, in 5,519 meters of water, scientists were successful in repeatedly reentering and deepening the drill hole, penetrating through 544 meters of basalt to a total depth of 868 meters below the sea floor. At this site, in contrast to other deep penetrations, the observed magnetic patterns show a correlation between the magnetic properties of the upper layer of basalt and the regional magnetic anomalies. By achieving deeper penetrations at more locations, scientists will be able



**Deep Sea Drilling Project.** Scientists aboard *Glomar Challenger*, operating in the Atlantic Ocean south of the Bermuda Rise, examine basalt recovered from a deep hole drilled under more than 5 kilometers of water. Penetrations like this, which drill nearly a kilometer below the ocean floor, provide important data for understanding the structure of ocean basins.

to evaluate the existing theoretical model of ocean floor structure.

In May 1977, *Glomar Challenger* returned to the Pacific Ocean and for the rest of the year operated in three regions: near the crest of the East Pacific Rise, on the southern flank of the Galapagos Rift zone (northeast of the Galapagos Islands), and on the Emperor Seamounts (northwest of Hawaii). Drilling on the East Pacific Rise was aimed at obtaining samples of geologically youthful crustal rocks from a rapidly spreading mid-ocean ridge for comparison with samples obtained earlier from the slower spreading Mid-Atlantic Ridge.

Leg 55 was devoted to drilling on the Emperor Seamounts, a long chain of submarine volcanoes that is probably a continuation of the Hawaiian group. The entire Hawaiian-Emperor chain is believed by some to have been formed in the process of sea-floor spreading by the passage of the Pacific Ocean floor over a single "hot spot" in the Earth's mantle, the "hot spot" presently being located beneath the volcanically active island of Hawaii. Drilling on four of the Emperor Seamounts showed them to be older but otherwise typical Hawaiian-type volcanoes, thus supporting the "hot spot" theory.

of energy and mineral resources, waste disposal, and environmental protection.

The continuing goal of NSF's ocean programs is to improve understanding of the nature of the ocean, its influence on human activities, and, conversely, our impact on the marine environment. As the Earth's population continues to grow and as technological advances increase the possibility of damage to the environment, it becomes more important to understand the present nature of the marine environment, the increasing effects of our activities on the oceans, and the basis for rational preservation and use of this global resource. Progress toward improved understanding is made through three major programs: One basic research program supports projects of individual scientists largely at the academic institutions; a second supports a limited number of large, managed projects; and a third program provides for the acquisition and operating costs of the ships and other oceanographic facilities needed to carry out these research programs.

More than 300 grants were made in fiscal year 1977 to individual scientists for developing fundamental knowledge about the oceans, their contents, and the sea floor. Investigations concentrated 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

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## Ocean Sciences

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NSF's ocean sciences program supports the major share of basic oceanographic research in the United States. This research, performed almost exclusively by academic in-

stitutions, provides the basic understanding of oceanic processes required by the mission agencies in their roles in national defense, environmental prediction, fisheries, location

providing about 75 percent of the support for 29 research ships and a number of specialized facilities; these are scheduled on a shared-use basis. NSF also supports, through this program, a continuing effort to evaluate and upgrade the facilities necessary to sustain a viable oceanographic research effort at the Nation's universities.

### Direct Observation of Blue-Water Plankton

More than half the Earth's surface is covered with the clear, blue water of the open ocean. The sparkling clarity of this vast environment indicates a shortage of the nutrients needed to support plant growth, and, correspondingly, there is a dearth of phytoplankton (minute plants). Our understanding of animal life in this dilute environment, however, has been derived largely from samples taken with nets. In fact, such samples yield only a partial picture of fauna of the open sea, because delicate gelatinous organisms, a major component of the zooplankton, are usually destroyed or damaged beyond recognition. Furthermore, small-scale spatial associations among the organisms are totally lost in net samples. Richard Harbison and Laurence Madin and their colleagues at the Woods Hole Oceanographic Institution have taken a different approach and made SCUBA dives to depths of 30 meters (100 feet) in the open sea to make direct observations on living plankton in the sunlit upper waters.

Their studies have confirmed earlier observations on the diversity, abundance, and probable importance of the gelatinous forms too fragile to be sampled effectively with nets. These beautiful, delicate organisms, which range in evolutionary position from simple jellyfish to their complex vertebrate relatives, the salps, comprise the majority of animals in this upper layer. Despite this taxonomic



**In search of plankton.** At the surface of the ocean, with several miles of water beneath him, Laurence Madin of Woods Hole Oceanographic Institution gathers delicate and nearly transparent animals in glass jars for later study (the spear, carried during early dives, was to ward off sharks, a hazard that did not materialize). This meticulous method of sample collection and observation is providing insight into important life processes in the open ocean.

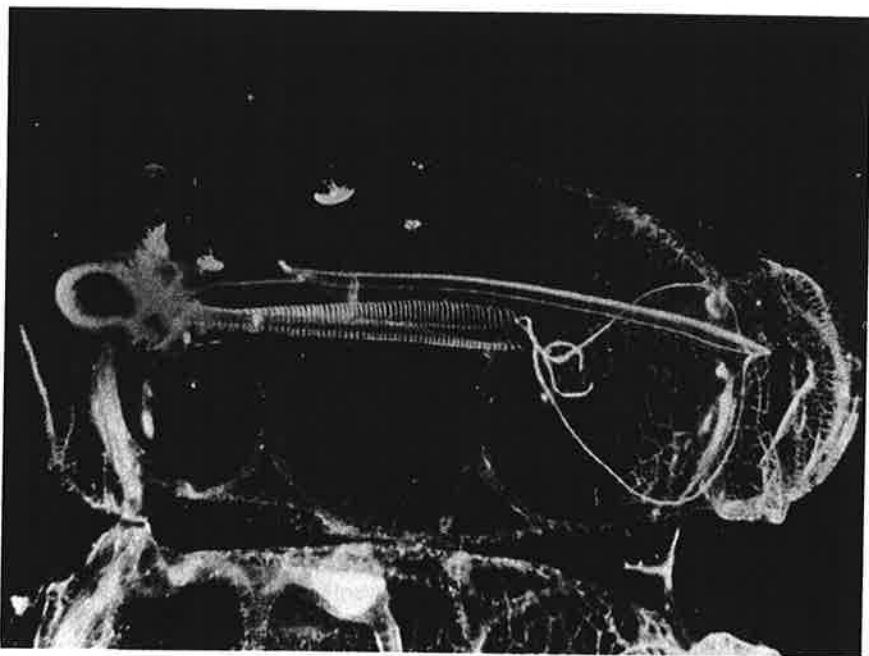
diversity, they show a number of similar adaptations for survival in this environment, including the fact that most are transparent.

Harbison and Madin have found that salps, in contrast to crustacean zooplankton, are able to feed on a very broad range of particle sizes—from the tiniest phytoplankton cells to large crustacean zooplankters—indicating that they have maximized their ability to capture food from this sparse environment. Salps produce a feeding net of sticky secretions and periodically roll up and ingest the net and its captured particles. Since salps feed voraciously and often occur in dense swarms, they can easily decimate patches of phytoplankton. This feeding activity may subsequently stimulate further phytoplankton growth since measurements of the nitrogenous excretions of salps and other gelatinous forms indicate that

they are important in recycling the limited amounts of nitrogen available for plant growth. Rapid cycling of nitrogen between grazers and phytoplankton helps prevent its loss from surface waters as sinking particulate matter.

This direct observation is also beginning to answer a question that has long puzzled marine biologists. Ecological theory suggests that zooplankton of the seemingly featureless open ocean environment should have low species diversity because species must use available resources in nonoverlapping ways, and mid-ocean food resources are limited. Yet mid-ocean zooplankton are extremely diverse. Harbison and Madin have resolved part of this apparent conflict with their careful observations of the relations between animals. Gelatinous animals frequently host amphipods, small crustaceans





**Oceanic planktonic animals.** The associations between gelatinous animals of many varieties and amphipods have been found to be widespread in the surface waters of the ocean. Amphipods use the host animals as places to feed and to raise young. In this case, a single small amphipod sits inside a jellyfish-like animal. (Photo by Laurence Madin/Woods Hole Oceanographic Institution)

better known from the floor of the sea where they live on solid substrates. The amphipods cling to salps and other animals and feed either on their host's tissues or on the food that the host has gathered. Some species of amphipods are found only on a single host species, and one amphipod with largely free-swimming adult stages utilizes a salp host as a nursery for its young.

These specific interactions are evidence that plankton communities are not the thoroughly mixed, random soup of large numbers of species as they appear in net samples, but consist of numerous coevolved and coadapted associations of interdependent organisms. The gelatinous animals appear to provide a solid substrate and a diversity of food resources for the amphipods and thus give structure and complexity to an environment that on superficial examination appears featureless and simple.

### Ocean Floor Seismology

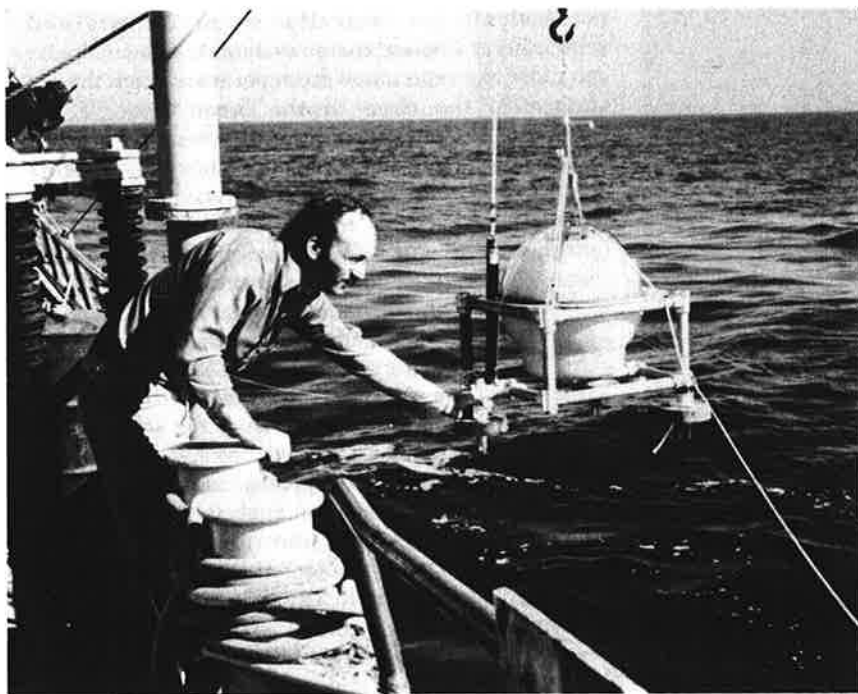
The many seismic refraction profile experiments done in the ocean basins during the past 30 years have led to a generalized model of the oceanic crust. This model indicates that below a thin layer of sediment, which is often not measured by sea surface seismic refraction techniques but which is seen by seismic reflection profiles, there is a zone—layer 2—with seismic velocities between 4 and 6 kilometers per second. Below this zone is the so-called oceanic layer—layer 3—with velocities between 6 and 7.5 kilometers per second. These layers were introduced by the early seismologists as a convenient way of presenting their travel-time data.

The recent development of ocean bottom seismometers (OBS) has now allowed a more detailed picture of the structure of the ocean crust to be developed. Using an OBS unit, which

is basically a self-contained seismometer system, the seismologist can move the experiment from the sea surface to the ocean floor. Three immediate scientific benefits are obtained. First, sea-floor instruments can measure shear waves in addition to the compressional seismic waves (which are the only type transmitted through the water column). Second, the seismometers are approximately 5 kilometers (the depth of the oceans) closer to the geologic structure. Third, experiments are not constrained to a single research ship; the scientist can deploy a number of individual units and use modern array processing mathematical analysis techniques to determine the geologic structure. Using this technique, L. Dorman and J. Orcutt of Scripps Institution of Oceanography and B. Lewis of the University of Washington have recently developed a more detailed understanding of the seismic velocities of the oceanic crust. Their interpretations suggest that the top 1.5-kilometer section of the oceanic crust, equivalent to the old layer 2, has a large velocity increase with depth for seismic waves. The underlying layer 3, the oceanic layer, also has a noticeable, but much smaller, velocity increase with depth. The base of the crust, the Mohorovicic discontinuity, is marked by a distinct break in the seismic velocity profile with a jump in velocities to over 8 kilometers per second.

In two cases over the East Pacific Rise there is evidence for velocity reversals or low velocity zones within the oceanic crust. A similar experiment over the Mid-Atlantic Ridge, however, indicated no evidence of a low velocity zone. The details of the velocity gradients also appear to be strongly dependent on the age of the sea floor and the structural setting. Thus, the early models of broad-scale uniform geologic structure for large areas of the ocean basins are proving to be oversimplified.

The seismic models are now being



**Sea floor data.** Aboard the University of Washington's *R/V Thompson*, a technician lowers an ocean-bottom seismometer, which operates remotely as part of an array of instruments to reveal the structure of the Earth's crust beneath the sea. Findings from this work off Central America are forcing some revisions to earlier models of the structure of ocean basins.

coupled to petrologic and geochemical results from the Deep Sea Drilling Project, to marine magnetic and electromagnetic models, and to improved thermal and tectonic models for ocean crustal generation processes. These integrated models suggest the low velocity zones may be pockets of partially melted rocks, or magma chambers, which are the source of the new ocean crust generated at sea-floor spreading centers.

### Water Motion on the Continental Shelf

The Continental Shelf is the region of the ocean that connects the coast with the deep ocean. The relatively shallow depths over the shelf often allow the stresses from winds acting

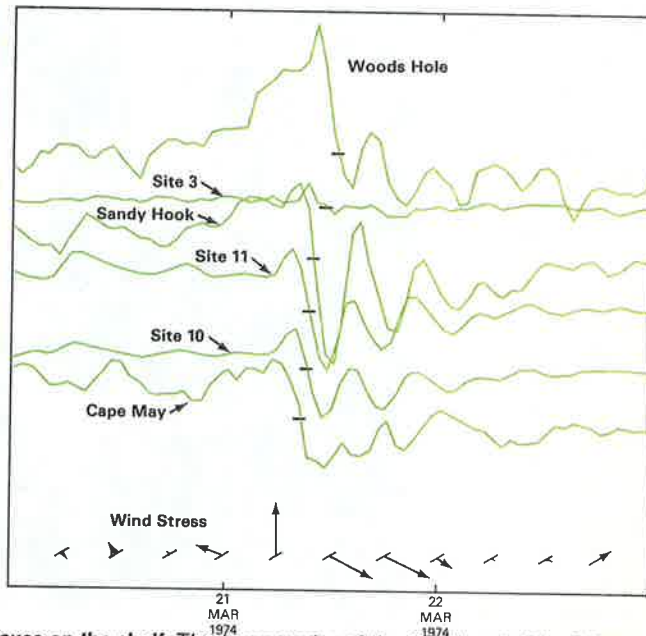
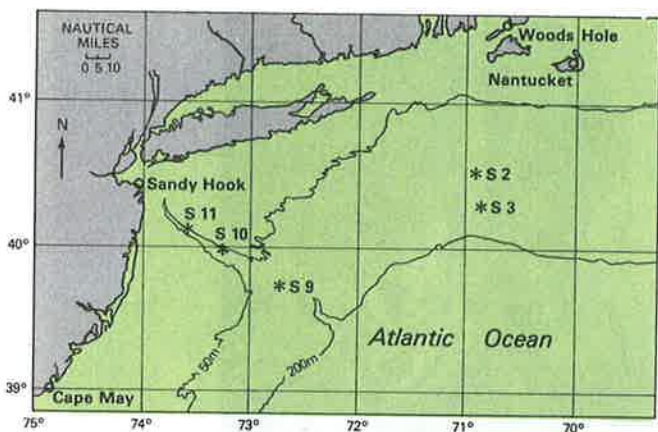
on the surface to penetrate all the way to the bottom. As a result, strong currents can exist in the shelf waters. Moreover, the sharp change in depth at the shelf break acts as a "hydrodynamic barrier"; consequently, the shelf waters are essentially decoupled from the motions in the deep ocean beyond the continental slope.

Circulation of the waters over the shelf directly affects coastal regions in a number of ways, driving motions in harbors and estuaries and transporting the outflows from rivers and discharges from coastal cities away from the coast. Research and monitoring activities on the Continental Shelf are being supported by a number of Federal agencies, with NSF-supported studies focusing on understanding specific mechanisms responsible for the observed motions.

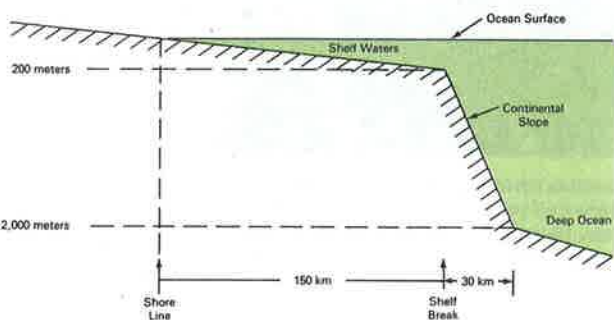
Data from recent experiments carried out at different locations in the Mid-Atlantic Bight by National Oceanic and Atmospheric Administration (NOAA) and NSF-supported researchers have been combined to give a more comprehensive picture of the region as a whole. In that work Robert Beardsley and colleagues at the Woods Hole Oceanographic Institution mounted an array of pressure recorders on the bottom of the shelf off Woods Hole, Mass.; a similar array was deployed off New Jersey by NOAA investigators. These instruments record bottom pressure, which is a direct measure of sea level at that point. Fluctuations in sea level may then be compared from one point to the next and related to shore-based measurements from tide gauges. Most of the fluctuations in sea level are due to tides and are predictable to a high degree of accuracy. Modern instrumentation and mathematical techniques then allow one to subtract the tidal fluctuations from the actual pressure record and study the remaining fluctuations, which are indicators of the nontidal circulation.

In one set of their records, Beardsley and his colleagues discovered a packet of waves that appeared to propagate northeastward along the coast from Cape May to Woods Hole. Investigation of meteorological conditions showed that these waves must have been produced by the strong winds associated with a sizable storm that moved along the coast at about the same time. These waves, which are interpreted to be coastal trapped edge waves, are forced to remain near and propagate along the coast by the effect of the shelf-break topography. The motions can be very roughly but very simply visualized by picturing the shelf water as a slab flopping up and down at the coast and hinged at the shelf break. The oscillations died out in a period of about 18 hours.

These results show that intense storms moving in certain directions



**Waves on the shelf.** The topography of the Continental Shelf (lower left) creates a near-shore ocean environment in some ways isolated from the deeper ocean. In a recent experiment (upper left), a series of sensors, which measure tidal fluctuations, between Cape May, N. J., and Woods Hole, Mass., recorded the passage (above) of a group of storm-induced waves that traveled along the coast. The resulting change in coastal sea level caused by the storm alone was as great as a meter.



can excite large-scale high frequency water motions that travel along the mid-Atlantic shelf. The change in sea level at the coast due to these waves can be as large as a meter. Clearly, if these motions are in phase with a strong tidal signal, they can produce significant effects on coastal cities, harbors, and beaches. These and other phenomena must be better understood to predict their effects on the coastal zone.

### International Decade of Ocean Exploration

As part of the International Decade of Ocean Exploration seabed assessment program, scientists are investigating the theory that seawater circulating in the top few kilometers

of the oceanic crust extracts metals and deposits them as metal-rich sediments on the sea floor. To test this idea, scientists from the Woods Hole Oceanographic Institution, Oregon State University, the Massachusetts Institute of Technology, Stanford University, and the U. S. Geological Survey made 24 dives to the Pacific Ocean floor in the research submersible *Alvin* during February and March of 1977. Two hundred miles northeast of the Galapagos Islands and nearly 2 miles beneath the ocean surface, scientists found four active and three extinct hydrothermal vents along the Galapagos Rift Zone.

From *Alvin's* windows the scientists saw hot water geysers that spewed from cracks in new, hardened lava and sent plumes of chemically rich brine

into the cold, surrounding water. The surface of new lava, untouched by sediments, was stained bright red, orange, white, and gold, showing the signs of freshly precipitated minerals. Water from the springs was as much as 15° C (27° F) higher than the usual 2° C (36° F) found at depths of nearly 2,700 meters (9,000 feet). Over 700 liters of hydrothermal waters were collected by *Alvin*, and its remote collectors also sampled suspended particle matter, metal-rich sediments, and basalt. Scientists aboard the *R/V Knorr* conducted an extensive heat-flow survey while the diving was in progress.

The scientists were surprised to find an abundance of life near the vents. These included clams nearly a foot long, dense populations of



mussels, crabs, sea anemones, limpets, chitons, and clusters of organisms that look like dandelions. A prevailing theory is that sulfide bacteria are at the base of the food chain in the vents and live on hydrogen sulfide in the discharging water. If this is the case, the vent communities are the only known communities in which the ultimate food source is not based on sunlight.

The processes of continental evolution are also being investigated under the seabed assessment program's Studies in East Asia Tectonics and Resources (SEATAR). Geological and geophysical data collected along a transect at right angles to the Java Trench (near Sumatra) direction show the ocean crust slipping under the island arcs. The uplifted island arcs show the relationship between shallow structures and sedimentation in the subduction zone. Survey data from across the Banda Arc in eastern Indonesia show that the Australian continental margin is also sliding under the island arcs. There, the late stages of subduction can be observed as the Australian Continent becomes welded to the Asian Continent.

As part of the environmental forecasting program, research on water temperature conditions in the northern Pacific has provided the basis for 3-month predictions of weather patterns across North America. Scientists working on the North Pacific Experiment (NORPAX) predicted the abnormal winter experienced across the United States during the winter of 1976-77; compared to the observed weather, the forecast proved to be reasonably accurate.

The forecast uses a prediction technique developed as a part of the NORPAX program by Jerome Namias of the Scripps Institution of Oceanography. North Pacific sea surface temperature patterns in the fall are predicted to evolve into a winter pattern, which is then translated into an atmospheric flow



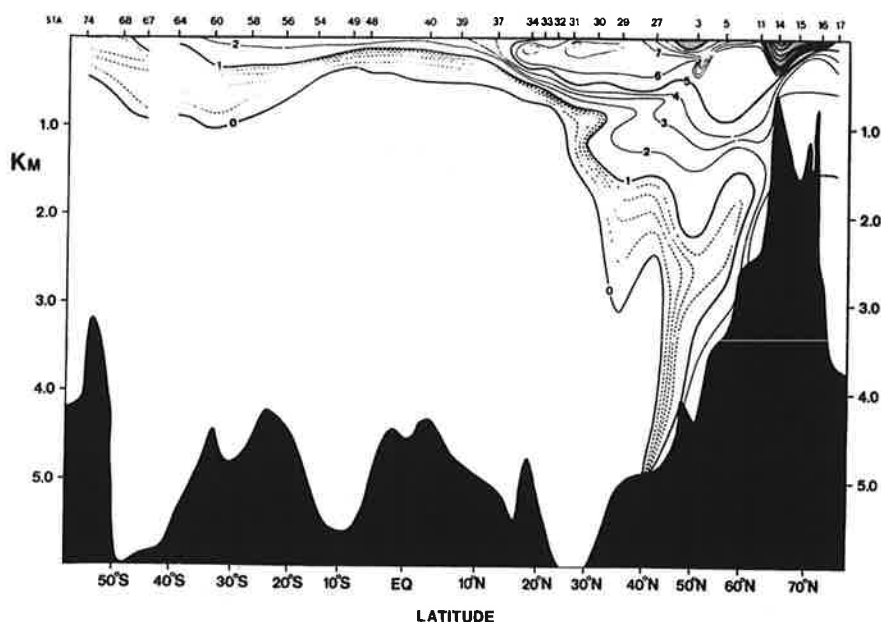
**Life at the bottom.** An external arm on the submersible *Alvin* reaches out to sample warm water discharging from hydrothermal vents nearly 3 kilometers deep in the Pacific. The unusual marine community around the vents may be based on bacteria which feed on hydrogen sulfide in the vents; if so, it would be the only known community not based on solar energy.

pattern over the ocean. Based on anticipated air currents from the ocean, NORPAX researchers predicted a strong atmospheric ridge over western North America and a strong trough over the U.S. east coast. The result of this atmospheric pattern was domination of the eastern two-thirds of the United States by frigid air and snows while the far west suffered under drought conditions.

In the environmental quality program, oceanographers prepared for a detailed survey of the Indian Ocean as the conclusion to the Geochemical Ocean Section Studies (GEOSECS) program. Combined with data from earlier cruises to the Atlantic (1972) and the Pacific (1973-74), the Indian Ocean data will provide the most comprehensive and detailed data of the geochemical features of the world's ocean yet collected. Many of the elements selected for intensive study are radioactive and come from

known geographic areas. Knowledge of where these isotopes enter the oceans makes it possible to describe mixing processes a considerable distance from the sources. Tritium, a hydrogen isotope with a half-life of 12 years, has already enabled scientists to trace water masses sinking in the Arctic and to estimate the rate at which carbon dioxide is absorbed from the atmosphere by the ocean.

Six U.S. ships joined scientists from Peru, Chile, Canada, France, and the Soviet Union for JOINT-II, the final field experiment in the Coastal Upwelling Ecosystem Analysis (CUEA) project. The goal was to link the physical and chemical changes associated with coastal upwelling to the resulting biological products. Earlier work by the CUEA team off Oregon, Baja California, northwest Africa, and Peru found that a counter undercurrent is always present in productive upwelling ecosystems.



**Tracing water.** Tritium, a radioactive isotope of hydrogen, has proven to be a valuable tracer of the long-range movement and mixing of water masses in the oceans. This north-south ocean profile of the western Atlantic, compiled from water samples taken during 1972-73, shows the movement of tritium-dosed water away from two areas (cross hatched) where it presumably entered the water following high latitude Soviet atom bomb tests in the early 1960's. (Concentrations are in tritium units—tritium/hydrogen  $\times 10^{16}$ .)

Moreover, the strength and location of this undercurrent exerts a powerful influence on the biological character of the upwelling ecosystem. In 1976 subtle but large-scale changes occurring in the Peru-Chile undercurrent had dramatic biological consequences. A single species of phytoplankton dominated the coast of Peru all the way from Ecuador in the north to Chile. Also present were dense shoals of jellyfish and, in one region, a distinct zone of hydrogen sulfide. These conditions almost completely wiped out the anchovy stocks spawned in 1975.

During JOINT-II the "unusual" 1976 conditions characterized by the undercurrent reversals ended, and by 1977 conditions closer to the long-term average conditions returned to the coast of Peru. It was very clear by the end of the project in June 1977 that a period of cooling and strong upwelling had returned, marking the

end of unusual conditions that had begun in 1975.

As the IDOE nears the end of its 10-year span, steps are being taken to define the goals and guidelines necessary to maintain the capability to support long-term, multidisciplinary, multiinstitutional ocean studies. As part of this planning process, a joint steering committee from the National Academy of Sciences-National Academy of Engineering organized a September 1977 workshop in Seattle, Wash. Some 80 participants, including marine and social scientists, laboratory administrators, Federal agency officials, industrial managers, and foreign scientists took part in discussing the research needs and opportunities for large-scale, long-term oceanographic research during the 1980's. The main basis for these discussions was a series of disciplinary workshops held in the spring of 1977 at the University of Rhode Island, plus

extensive mail comments from the marine affairs community. A report with recommendations from these sessions is anticipated in early 1978.

## Oceanographic Facilities and Support

Oceanography is predominantly a field-oriented activity. The oceanographer must collect and analyze data at sea, test and evaluate theoretical concepts and equipment, and gather specimens and samples for further experimentation in laboratories ashore. Specialized platforms such as submersibles and aircraft are important tools; and "remote sensing" from unmanned platforms such as satellites, buoys, and moored equipment arrays is a rapidly developing field. Nevertheless, the 29 surface ships comprising the "academic fleet" continue to be indispensable for most oceanic research.

The Foundation's preponderant position in support of oceanographic research is reflected in its lead role in support of the academic fleet. In fiscal year 1977 approximately two-thirds of fleet operations were in support of NSF projects. In addition to serving NSF's ocean sciences programs, the fleet is also an important adjunct to many other Foundation-supported programs that derive data or research materials from the marine environment. These include biomedical research in metabolic processes, neurobiology, and physiology; atmospheric research, particularly in climate dynamics and long-range environmental forecasting; and geological and geophysical investigations by terrestrial rather than submarine specialists. The complex task of scheduling and operating these ships is carried out by 15 academic institutions. To coordinate these efforts and to provide a scheduling clearinghouse for scientists based at other institutions, all ship operating laboratories are members of

UNOLS—the University-National Oceanographic Laboratory System.

NSF's oceanographic equipment program is the primary source of support for upgrading academic fleet ships and for enhancing their scientific capabilities. The first concern of the program is, of course, the safety and seaworthiness of the ships themselves. In fiscal year 1977, a 3-year effort was completed to bring the fleet into full compliance with existing and pending environmental regulations. This required major structural changes to four of the largest vessels to replace saltwater-compensating ballast systems with more environmentally sound alternatives. With the space limitations of ships, handling of solid wastes, trash, and sewage has become extremely complicated. A number of fleet ships have been fitted with industrial-type trash compactors, and several engineering and feasibility studies have been funded in anticipation of a major push to upgrade shipboard waste-handling in the next few years. Although these items seem mundane, they are essential to the fleet's continued operation, and their cost and complexity require careful planning.

Other equipment awards lead to development of new instrumentation to enhance shipboard research capabilities. During fiscal year 1977 the University of Miami completed design and prototype testing of a new satellite communications system. Under the direction of Otis B. Brown and Robert H. Evans, the Miami team developed a reliable low-cost system that can be used for ship-to-shore communications and, more significantly, for data transmittal. The space, power, and maintenance requirements of shipboard computers have tended to limit their use to a few large ships or awkward temporary modular installations. The Brown/Evans system, built largely of inexpensive off-the-shelf electronics components and microprocessing units, can convert raw data to compati-

ble format, transmit them via satellite to a shore computer for processing and receive the processed data back aboard the ship. This provides a near real-time capability that is adequate for many research applications. The system is so compact that it can be carried from ship to ship in a small suitcase. In addition to the Miami ships, *Gilliss* and *Iselin*, several other academic fleet ships have used the prototype units successfully. A UNOLS workshop is planned during 1978 to explore other applications.

The Foundation's ship construction and conversion program supported several ship design studies during 1976 and 1977, looking toward renewed construction activity in the 1979-83 period. Ships in the 25- to 42-meter (85- to 140-foot) size range are needed for many types of coastal and near-shore research. This category is underrepresented in the current fleet, and several of the older, obsolete

vessels on the replacement schedule fall in this class. Several conceptual design studies were carried out by groups representing potential operating institutions and scientific users of various geographic regions. The preliminary design reports were subjected to detailed technical evaluation, and two were identified as particularly worthy of further development.

Another design effort, this one representing a national scientific constituency, produced a conceptual design for an ice-strengthened ship for polar service, a capability absent from the present fleet. This design, too, has been recommended for further development. The University of Alaska, which heads the design group, has also undertaken design of a larger version of the ship for consideration as a possible eventual replacement for the *Islas Orcadas* (ex-*Eltanin*) for antarctic research service.

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## United States Antarctic Research

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Most of the world's known meteorites have been found by chance. Yet, since 1969, organized searches in Antarctica have turned up nearly a third of all meteorites known to science. Eight years ago a Japanese survey team in the Queen Fabiola (Yamato) Mountains of east Antarctica found nine meteorites lying exposed on the ice sheet; later Japanese searches resulted in findings of an incredible 992 specimens.

In December 1976 and January 1977, William A. Cassidy of the University of Pittsburgh, Edward J. Olsen of Chicago's Field Museum of Natural History, and Keizo Yanai, who had participated in the original Japanese discoveries, used a helicopter to search for meteorites near the Transantarctic Mountains of southern Victoria Land—3,200

kilometers from the Queen Fabiola Mountains. This search, too, was successful: The team found 11 meteorites in 40 days. One of the meteorites weighed 407 kilograms; it is one of the world's larger meteorites and is the largest ever found in Antarctica.

The antarctic meteorites were found lying exposed on bare ice surfaces at places where the continental ice mass had lost its snow cover and apparently is losing mass by sublimation. The meteorites were found where mountains, projecting through the ice sheet, dam the ice and prevent its movement to the sea. The investigators concluded that local concentrations of meteorites could be found at many such sites in Antarctica.

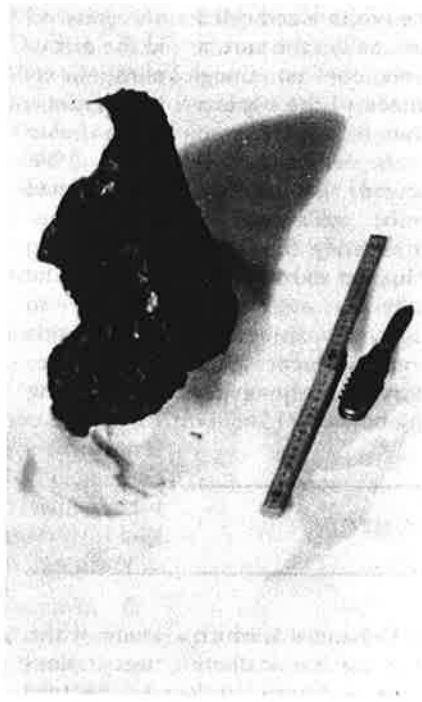
Meteorites are of scientific interest

not only as the only extraterrestrial material available (except for the lunar samples), but also because their chemical and rock characteristics give clues to the history of the solar system. Antarctic meteorites are especially interesting because the cold, relatively sterile antarctic region inhibits weathering and terrestrial contamination. Further searches are planned. The team hopes to find a meteorite containing organic molecules, which may help exobiologists in their search for the origins of life.

As the Earth's largest heat sink, or area of cold, Antarctica has a large influence on global atmospheric circulation. Trends in antarctic temperatures have global implications. At its scientific outpost at the geographic South Pole, the United States has made daily observations of temperature since January 11, 1957.

Werner Schwerdfeger, a University of Wisconsin meteorologist, has analyzed the 20-year record. He has observed two remarkable features of the temperature regime. First, the south polar "summer" is short: not more than 30 days between mid-December and mid-January deserve that name. Just 2 weeks later, the average temperature already is 8° C below the warmest days. This early and fast cooling contributed to the tragic end of Robert F. Scott's expedition in 1912. Second, the south polar winter is "coreless": already in the last days of March it is nearly as cold as the six following months.

The December mean for the 20-year period is -27.8° C; the July mean, -60.1° C. South Pole Station recorded its coldest winter in 1976, when the April to September mean was -60.7° C. There is, however, no trend. The mean temperature for the first 10 years exactly equals the mean for the second 10 years: -49.3° C. Of course, South Pole Station is only one point on a 14-million-square-kilometer continent; some coastal measurements suggest a warming trend.



**Antarctic meteorite.** A combination of climatic and topographic conditions in Antarctica results in the local accumulation of meteorites at predictable locations. This 20-kilogram meteorite is one of nearly 1,000 found there in the past 8 years.

Investigators from several U.S. and Argentine institutions collected geological, geophysical, and physical oceanographic data during two 60-day cruises of the ice-strengthened research ship *Islas Orcadas*. Totalling 15,550 nautical miles, the cruises crisscrossed the seldom-explored southern ocean sector between South America and Africa. Geophysical data collected during the cruises enabled delineation of four spreading centers offset by geological faults. One of these, at 7° E. 54° S., was named the *Islas Orcadas Fracture Zone*. Material scraped from the surface of the northwest wall of the zone suggests a great thickness of periodite of uniform composition, indicating the presence of upper mantle. Previously, the upper mantle has been reached only by deep drilling.

For years, glaciologists have been using the chemical composition and oxygen-isotope ratios in polar ice cores to determine past climate. Now, Bruce C. Parker, a botanist at Virginia Polytechnic Institute and State University, and Edward Zeller, a University of Kansas geophysicist, have discovered that changes with depth in the amount of nitrogen compounds in an ice core from the South Pole may correlate with the 11-year cycles of sunspots, auroral activity, and cosmic ray fluxes. Parker and his colleagues suggest that  $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$  concentrations may provide a new, simple, and useful tool for the measurement of past upper atmosphere phenomena.

Further, if the concentration of  $\text{NO}_3\text{-N}$  in the South Pole core is representative of the antarctic ice sheet, Parker and Zeller calculate that the average annual electrochemical and photochemical fixation of nitrogen oxides for continental Antarctica is 2,700 metric tons of  $\text{NO}_3$ . This suggests that the estimated global value of 7.6 million metric tons is too high. Downward revision of the global value will have important implications. For example, ozone combines with nitrogen in the stratosphere to form  $\text{NO}_3$ , resulting in depletion of the ozone. Also, manmade fluorocarbons are a catalyst to the reduction of atmospheric ozone. If the natural process is operating on a smaller scale than previously supposed, then the disruptions by man could have greater effect than previous calculations would indicate.

The 1976-77 austral summer culminated 20 years of continuous research by the United States in Antarctica. During the summer operating season, when transportation to and within Antarctica was feasible, over 300 investigators performed 85 research projects designed to elucidate the nature of Antarctica, its effect on such global processes as climate and ocean circulation, and its

living and nonliving resources potential. One hundred and eleven researchers and support personnel were wintering in 1977 at the four U.S. stations: McMurdo, South Pole, Siple, and Palmer.

The researchers themselves have also been the subject of research. A study of the 1976 winterers (February-September) at McMurdo and nearby Scott Base, a New Zealand installation, showed that, contrary to popular knowledge, nothing unique happens to the human immune system during the 8-month isolation.

The white blood cell counts remained essentially constant, as did the serum levels for immunoglobulins. Comparison of the winterers with a group flown in to McMurdo from the United States in early September 1976 showed that the two groups had similar numbers of colds of approximately equal severity. The long isolation did not appear to make the winterers especially susceptible to respiratory infection. These results should influence planning for space flights and other expeditions involving long periods of isolation.

and May 1976. Scientists from ten U.S. and Canadian research institutions collected air, ice, and ocean data from manned and unmanned stations plus aircraft and a submarine. This will be used in the development of a computer model to explain and to help predict changing polar climate patterns. Such a model is important for ship routing in the Arctic Ocean, but it also has wide importance because sea ice has a large role in modulating weather all around the Earth. The extensive data files resulting from the experiment, which terminated with a symposium in September 1977, are available for further research use from the Division of Marine Resources, University of Washington.

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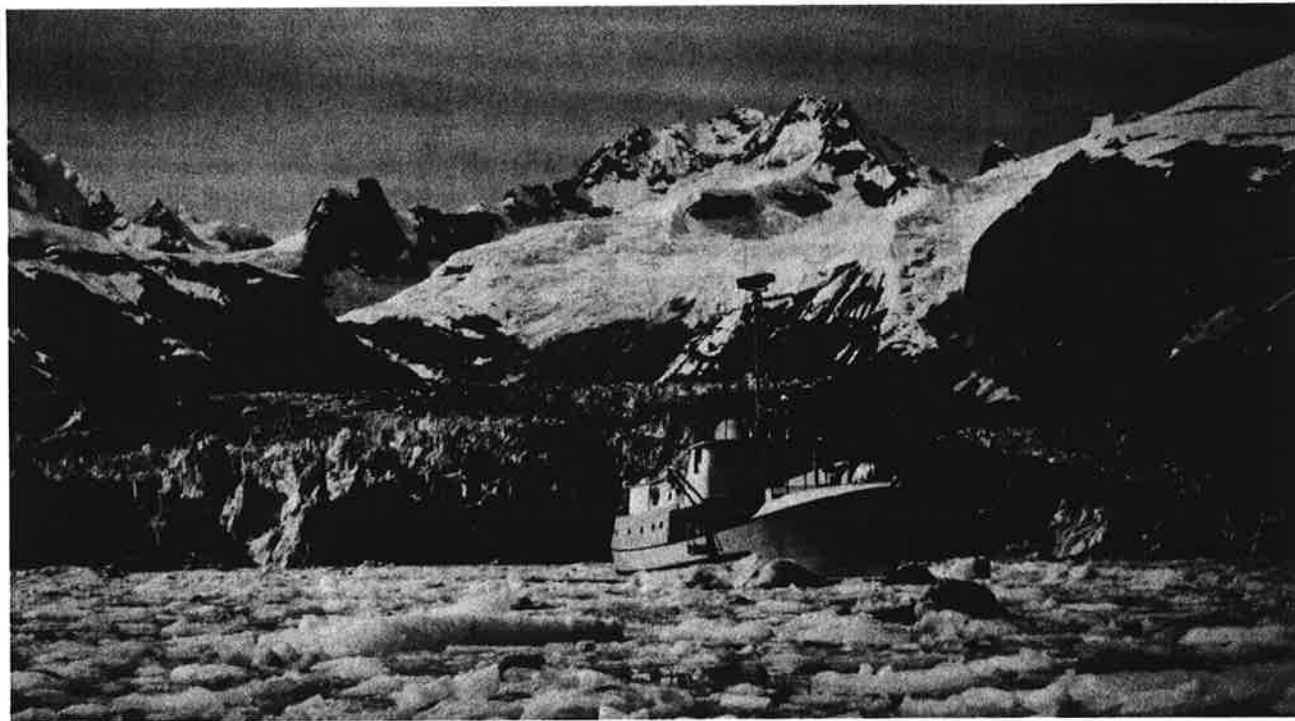
## Arctic Research

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The most complete documentation of sea ice motion yet available was compiled using data from the Arctic

Ice Dynamics Joint Experiment, which took place on drifting ice stations north of Alaska between March 1975

A geophysical and geochemical study of the Greenland ice sheet was begun in cooperation with Denmark and Switzerland; the objective is to



**Alaskan coast.** The University of Alaska's 85-foot research vessel *Acona* studied marine life on the Bering Sea shelf during the summer of 1977.

establish past climatic fluctuations and changes in ice sheet size. In the 1977 summer, holes for ice core retrieval and *in situ* measurements were bored to 175 and 82 meters in the south central region, four 100-meter cores were obtained near Camp Century, and four 100-meter cores were taken in north-central Greenland. Surface samples were collected near the western coast. The cores are now being analyzed along their lengths to determine chemical constituents and oxygen-isotope ratios; age, of course, increases with depth. The project builds on previous work, which included a core drilled to bedrock near

Camp Century in 1966, that established the validity of these methods for determining paleoclimate.

A study of the processes and resources of the Bering Sea shelf was begun in May of 1977. This Alaskan continental shelf is a productive fishing ground that shows high potential for subsea mineral deposits. The study is focusing on marine life and related physical and chemical forces, and the knowledge obtained will provide an ecological basis for managing the living resources. In the summer, data taken from 83 stations aboard the University of Alaska's research ship *Acoma* were used to

construct mesoscale models of the distribution and the survival rates of pollock eggs and larvae. Japanese and Soviet scientists are participating in the 5-year project.

Other projects in the arctic research program are studies of terrestrial and aquatic ecosystems at two sites on the North Slope of Alaska, of seismicity and paleomagnetism in Svalbard, and of the migration patterns of polar bears. On behalf of the Interagency Arctic Research Coordinating Committee, the Foundation published a report on all arctic research funded by the Federal Government in fiscal year 1977.







# Biological, Behavioral, and Social Sciences



The past year's research results in Biological, Behavioral, and Social Sciences are evidence that the pace of advance in these fields, which showed a dramatic increase in the early 1970's, has not abated. The antiquity of life, the development of man, and the functioning of hormones—all discussed in this report—are only a few topics we can speak about with greater certainty this year than was possible last year. Moreover, it is in the nature of the subject matter that the linkage between this fundamental undirected research and possible application is close. Progress toward the eventual solutions of problems involving health, agriculture, environment, population, and economics is dependent on advances in the disciplines that study these areas at their most basic levels.

The continuing vitality of these fields is seen in many ways. Both graduate and undergraduate enrollments are rising as students choose careers in research areas where they perceive that they can capitalize on intrinsically challenging intellectual opportunities and also contribute toward a better society. New Ph.D.'s in the biological, behavioral, and social sciences exceed those for all other disciplines and are an increasing percentage of total Ph.D. production. Moreover, this growth of interest is not restricted to new students; significant numbers of established scientists trained in physical, atmospheric, oceanographic, and computer science

are orienting their research toward biological, behavioral, and social science topics. This further stimulates research as new approaches, techniques, and methodologies expand scientific horizons. As an illustration of this sort of multidisciplinary ferment it might be noted that one of the corecipients of the Nobel prize for medicine in 1977 was awarded her Ph.D. in physics.

A direct measure of research activity is seen in the number of proposals received by NSF's 28 programs in the Biological, Behavioral, and Social Sciences. In fiscal year 1977 over 7,200 proposals were received—an increase of 1,200 over the preceding year. Reviews were solicited from more than 11,000 scientists in all parts of the

country and abroad, and almost 2,700 research grants were made.

This increasing scientific interest and capability in these areas is evident worldwide. Scientists from various nations have developed unique capabilities in different areas of science, and international exchanges of information and collaborative efforts are becoming much more common. For example, in the neurosciences, new fluorescence techniques for delineating brain structure have been developed in Sweden, and the Japanese have contributed new micromanipulative capability to neurophysiology. These advances, when combined with the dramatic new developments in neuroanatomy in the United States, permit the neuroscientist to begin to

**Table 4**  
**Biological, Behavioral, and Social Sciences**  
**Fiscal Years 1975, 1976, Transition Quarter**  
**(July 1-Sept. 30, 1976), and 1977**

(Dollars in Millions)

	Fiscal Year 1975		Fiscal Year 1976		Transition Quarter		Fiscal Year 1977	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Physiology, Cellular, and Molecular Biology .....	1,006	\$ 41.87	1,053	\$ 43.69	279	\$12.00	1,169	\$ 51.34
Behavioral and Neural Sciences .....	547	18.50	539	19.69	140	5.47	619	23.81
Environmental Biology ....	487	26.05	534	26.84	156	7.15	587	30.17
Social Sciences .....	359	17.75	364	18.81	100	5.11	375	21.29
<b>Total .....</b>	<b>2,399</b>	<b>\$104.17</b>	<b>2,490</b>	<b>\$109.03</b>	<b>675</b>	<b>\$29.73</b>	<b>2,750</b>	<b>\$126.61</b>

SOURCE: Fiscal Years 1977, 1978, and 1979 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

map the human brain in a more detailed and quantitative manner. This will ultimately permit more refined and effective neurosurgical techniques for medical purposes.

Science is truly an international entity, and nowhere is this more evident than in biological, behavioral, and social sciences. Worldwide we face many of the same problems—problems that depend on cooperative advances

for their resolution. These areas of science transcend national boundaries just as they transcend disciplinary boundaries. The ultimate goal is the acquisition of universal, generalizable findings which reflect both the unity and the diversity of life on this planet—from the fundamental molecules of living organisms to the complex interactions of human beings and their social institutions.

macromolecules. The new studies are designed to determine how proteins, lipids, and nucleic acids interact to form supramolecular structures or subcellular organelles such as ribosomes, chromatin, membranes, and viruses.

Scientists trained in biochemistry and genetics are newly attracted to the area of plant cell culture, where exciting advances are being made. Past barriers are being overcome; plant cell walls can be removed successfully, protoplasts can be fused, and subcellular parts can be inserted into protoplasts. As a result of this research, whole plants, including economically important crop plants, can be regenerated in the laboratory from cell suspension cultures. Continuing progress in this pioneering area should be highly rewarding.

The examples that follow illustrate several areas in modern cell biology where deeper insights into basic biological phenomena have become a reality and where opportunities for new thrusts are anticipated.

### Cell Culture Centers

Within the past few years a large number of biologists have focused their research on exploration of mammalian cells. These cells have become the new frontier of cell biology, and the challenge of understanding them is a logical extension of the research carried out with bacteria over the past decades.

Cells that have been isolated from mammalian sources and cultured in special media can be manipulated experimentally in a manner somewhat analogous to the handling of bacteria. Mammalian cells grow more slowly, must be handled more carefully, and cost much more to grow than bacteria. Not only are costs to provide cell culture facilities to each individual laboratory using cultured cells prohibitive, but, also, many significant research projects require more bio-

The nature of biological research, which underwent a major change starting nearly three decades ago, is now entering a new phase that promises to be even more revolutionary. It has as its foundation the discoveries and concepts of molecular biology, originally carried out with organisms as primitive as bacteria and viruses. Within the physiology, cellular, and molecular biology programs research continues to explain a broad spectrum of fundamental biological phenomena—an understanding at the molecular level of the cellular and subcellular activities that affect the entire plant or animal. The new burst of activities in modern cell biology is an extension of research from the molecular to the cellular level and, in particular, attempts to explain the interaction and regulation of molecular processes in cells, organs, and whole plants and animals.

Continuing technological advances and new methodologies have provided analytical probes with resolving power sufficient to permit the investigation of molecular phenomena of biological significance at the cellular level. Understanding the nature of the gene—the basic unit of heredity—and its functions is central to the objectives of cell biology. A major new effort in the study of genetic material is the isolation of individual genes to determine

the relationship between their structure and function and the ability to see the genetic material at the macromolecular level by sophisticated electron microscopy.

Research on recombinant DNA is a dynamic area at the forefront of science. A unique class of proteins, known as "restriction enzymes," allows the joining of two DNA molecules from different biological origins so that a hybrid or chimeric molecule may be constructed *in vitro* (i.e., outside the organism) under controlled laboratory conditions and subsequently incorporated into a host cell. This research technique has exciting theoretical and practical implications and will provide fundamental information concerning how genes are organized and controlled; how they function, replicate, and recombine; and, ultimately, how they can be manipulated to best serve our needs in biomedical, nutritional, and industrial areas.

Biochemists and biophysicists face a formidable challenge in explaining the structure and function of complex biological molecules. The study of the three-dimensional structure of individual molecules and its relationship to their function, which has been so successful for the past decade, is expanding to include an understanding of the interactions among

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## Physiology, Cellular, and Molecular Biology

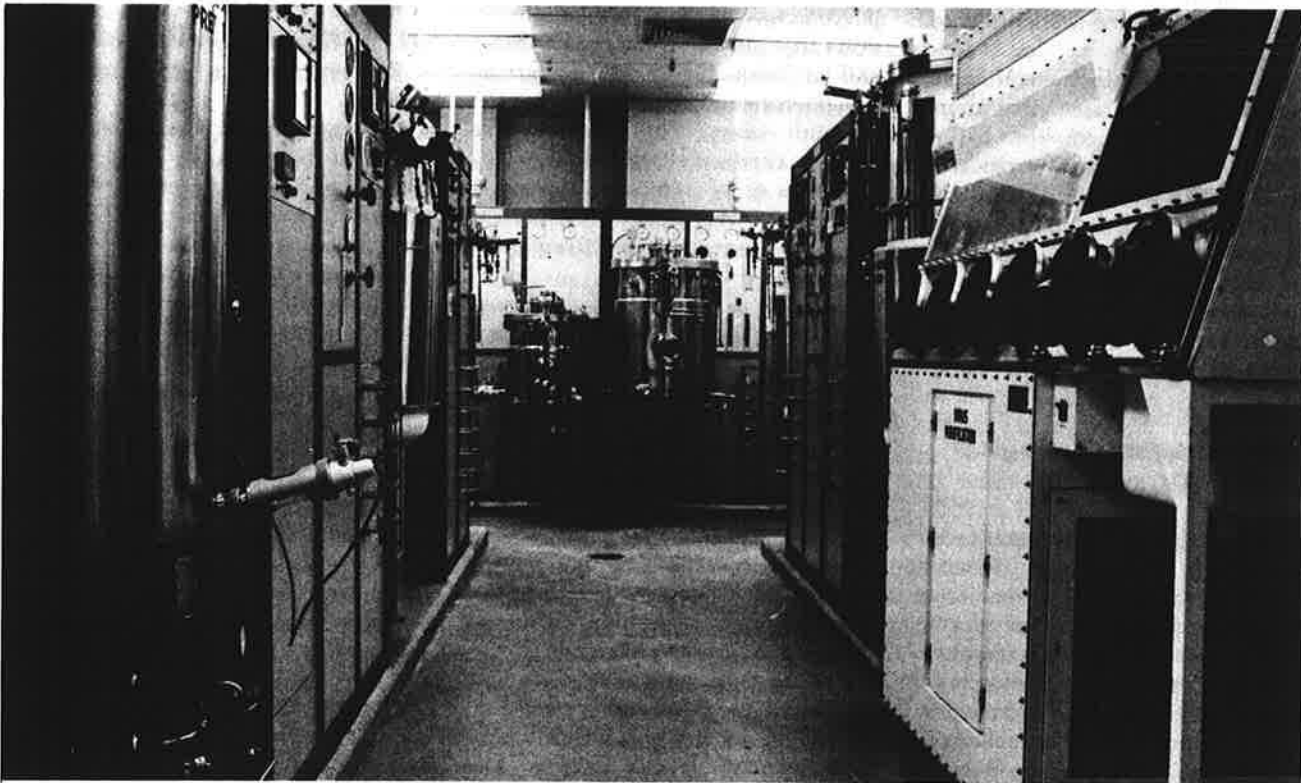
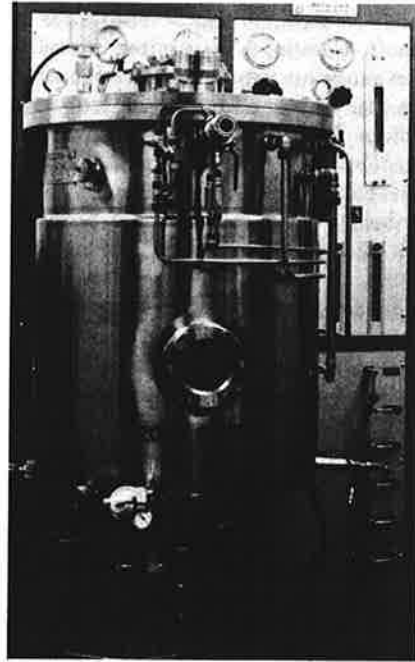
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logical material than can be produced in a normal research laboratory. In anticipation of the increasing pace of research in molecular cell biology, two cell culture centers were established to function as national research resources.

One center, at the Massachusetts Institute of Technology, is directed by Phillips Robbins of that institution and Richard Davidson of Harvard Medical School. The other center, at the University of Alabama at Birmingham, is directed by J. Claude Bennett of the department of microbiology and Ronald Acton of the Diabetes Research Center. These centers aim to: (1) produce cells that could not be readily obtained otherwise and are required for worthy research projects, (2) expedite efficient use of different cell fractions, and (3) develop and improve

methods of cell culturing and husbandry. Each center has an advisory committee. Prospective users submit applications that are screened by peer evaluation. If accepted, the applicants send seed cells, and the centers produce the desired amount of cells for the requested time.

The design of the MIT center permits large-scale use of standard cell culture methods; that is, roller bottles for cells that grow anchored on some material, and large flasks for cells that grow in suspension. The center is operating at a production level of approximately 14,000 grams of cells per year. David Levine, Daniel Wang, and William Thilly recently have developed a microcarrier that permits anchorage-dependent cells to grow suspended in culture medium. These microcarriers consist of sephadex



**Cell cultures.** One of two newly established centers for the production of mammalian cells for the research community is at the University of Alabama at Birmingham. This center and the one at MIT are important resources for rapidly growing research interests in mammalian cell biology.

beads coated with sodium carboxymethylcellulose. A number of cell types can adhere to the beads, which in turn can be suspended in the culture medium. Using this method, densities up to four billion cells per liter are achieved. At these higher densities, the number of cells yielded by a 5-liter flask equals that yielded by 200 roller bottles.

The design of the Alabama center includes a completely closed system of large-scale fermentation vessels and can accommodate a later stage of automated control. Although designed primarily for growing cells in suspension, the system permits the use of microcarriers in which anchorage-dependent cells can be grown. This center routinely produces a trillion cells per week and is trying to achieve a regular production level of ten trillion cells per week. Special effort is being devoted to the development of large-scale techniques for obtaining cell fractions.

The centers recently have produced large amounts of: Sindbis Virus for use in X-ray structural studies, SV 40 transformed 3T3 cells for purification and characterization of T antigen, specific mouse cells for isolation and structural analysis of a specific lysine transfer RNA implicated in the control of cell division, and BW5147 (mouse) cells for the isolation and structural analysis of H-2K and Thy-1 alloantigens.

### **Pheromones—Biological Attractants**

Certain chemical messengers called pheromones carry signals between individuals of a species. Female insects attract males of their species from long distances by emitting pheromones. Some pheromones attract insects of both sexes. The whole pheromone signaling system is a vulnerable facet of insect social behavior. Because insecticides are often toxic to harmful and beneficial species alike, even to man, and because insects can develop

resistance to toxic substances, interference with pheromones as signaling systems holds promise for insect control.

Pheromones, which can be isolated and synthesized in the laboratory, have been used in the field. In combination with insecticides, pheromones can increase the mortality of certain species without injuring others. By using pheromones as bait to trap certain insects, entomologists can monitor the abundance of particular insect species in a locality and improve the timing of insecticide applications with respect to the insect life cycle. Mass trapping of insects with pheromones is sometimes feasible, as is the disruption of normal mating by pheromones or pheromone inhibitors.

Robert M. Silverstein at the State University of New York College of Environmental Science and Forestry is studying the chemistry and biology of pheromones of bark beetles—forest pests that destroy trees and lumber—and has been able to isolate aggregation pheromones, which attract beetles of both sexes. His research also includes chemical characterization and synthesis of pheromones, as well as studies of insect behavior, especially the mechanisms of their perception of pheromones.

Wendell L. Roelofs, at Cornell University State Agricultural Experiment Station, has been studying moths of the family *Tortricidae*, including the red-banded leafroller moth, a major pest of apple orchards in the Eastern United States. He has isolated and chemically identified sex pheromones and discovered that sympatric species of insect (insect species that share a common environment) often respond to the same pheromones but in different mixtures. A particular sex attractant pheromone may attract one species of insect and repel another, depending on the presence of other compounds mixed with the pheromone. Species specificity of a pheromone mixture is thus a function of how the components are blended.

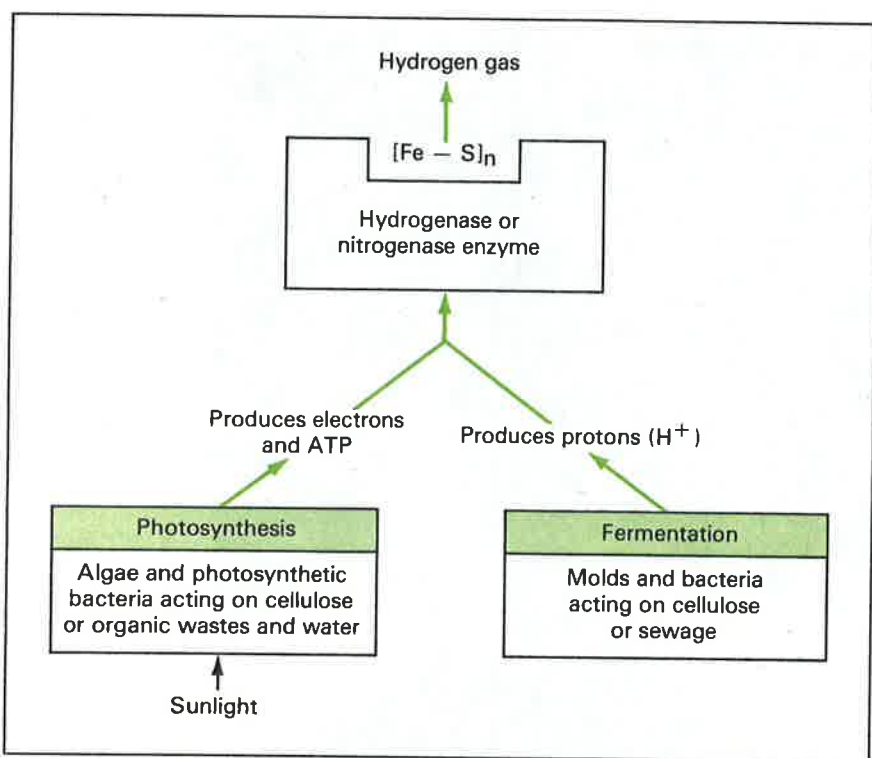
Research on these mechanisms, in addition to providing basic information on the evolution of insects and on the role of pheromones in reproductive isolation, can also make it possible to design blends of attractant that affect specific pest insects without disrupting other species inhabiting the same environment.

Vertebrates as well as insects use chemical pheromones as signals. F. H. Bronson of the University of Texas at Austin, Norman T. Alder of the University of Pennsylvania, and Gary K. Beauchamp, who is collaborating with Amos B. Smith III at the University of Pennsylvania, are studying olfactory communication in mice, rats, and guinea pigs. It plays an important role in sexual and social interactions in these rodent species. Smith and Gisela H. Epple are also studying scent marks used by primates for transfer of information.

### **Hydrogenase: A Biocatalyst for Hydrogen Production**

Hydrogen, the simplest element, is a beneficial fuel from the standpoint of both economics and nonpollution. Its extraction from the oceans, where it is present in water (a molecule of water contains two parts hydrogen to one part oxygen), would provide an inexhaustible energy source. This extraction requires reversing what happens when hydrogen molecules combine with oxygen molecules to form water. A biocatalyst, an enzyme called "hydrogenase," can activate either the "burning" (or oxygenation) of hydrogen to form water or the reverse reaction—the production of hydrogen from water—provided energy is available to support these conversions. The energy needed to produce hydrogen from water—equal to that released by burning hydrogen—can be provided by photosynthetic bioconversion of solar energy, as is done by green plants.

Active research on hydrogenase is under way in the laboratories of



**Enzyme-produced hydrogen.** A future system for producing usable hydrogen fuel from common raw materials might use a combination of photosynthetic and fermentation mechanisms to generate electrons, ATP, and protons, which are then combined by an enzyme—either hydrogenase or, using the ATP, nitrogenase—to make the burnable gas.

Martin D. Kamen and Nathan O. Kaplan at the University of California, San Diego, and Leonard E. Mortenson at Purdue University. Research on hydrogenase dates back to the 1940's when it was observed that the green alga, *Scenedesmus*, and the photosynthetic bacterium, *Rhodospirillum*, produced hydrogen gas when exposed to sunlight or artificial light. This photoproduction of hydrogen required that the cells be grown and illuminated in the absence of air. Subsequent work has shown that the hydrogenase enzymes are present in a large number of bacteria (e.g., *Pseudomonas*, *Rhodospirillum*, and *Clostridium*) and algae (e.g., *Chlamydomonas*, *Chlorella*, and *Scenedesmus*).

There are two types of photoproduction of hydrogen. In one, photosynthetic electron transport and

hydrogenase activity are independent of ATP—a ubiquitous molecule, found in all living cells, that stores up energy from sunlight in the form of chemical energy—and insensitive to nitrogen gas. In the other, the hydrogenase activity occurs as a corollary activity of the nitrogenase enzyme and is ATP-dependent and sensitive to nitrogen gas.

Basically, hydrogenase catalyzes the reversible equilibrium of molecular hydrogen with two protons and two electrons. The enzyme is able to remove two electrons from a molecule of hydrogen and transfer them to another receptor molecule; or it can accept electrons from another molecule (e.g., ferredoxin) and combine them with two protons to form a molecule of hydrogen. In general, the few hydrogenase systems examined so

far are so-called “nonheme” iron-sulfur enzymes, consisting of a tightly organized complex of four iron and four sulfur atoms linked to the protein portion. It is not known how this chemical complex acts on a molecule of hydrogen to decompose it or add electrons to produce a molecule of hydrogen. However, an efficient coupling of the water-splitting photosynthetic electron transport system with the hydrogenase system would, in principle, be able to produce hydrogen gas using solar energy.

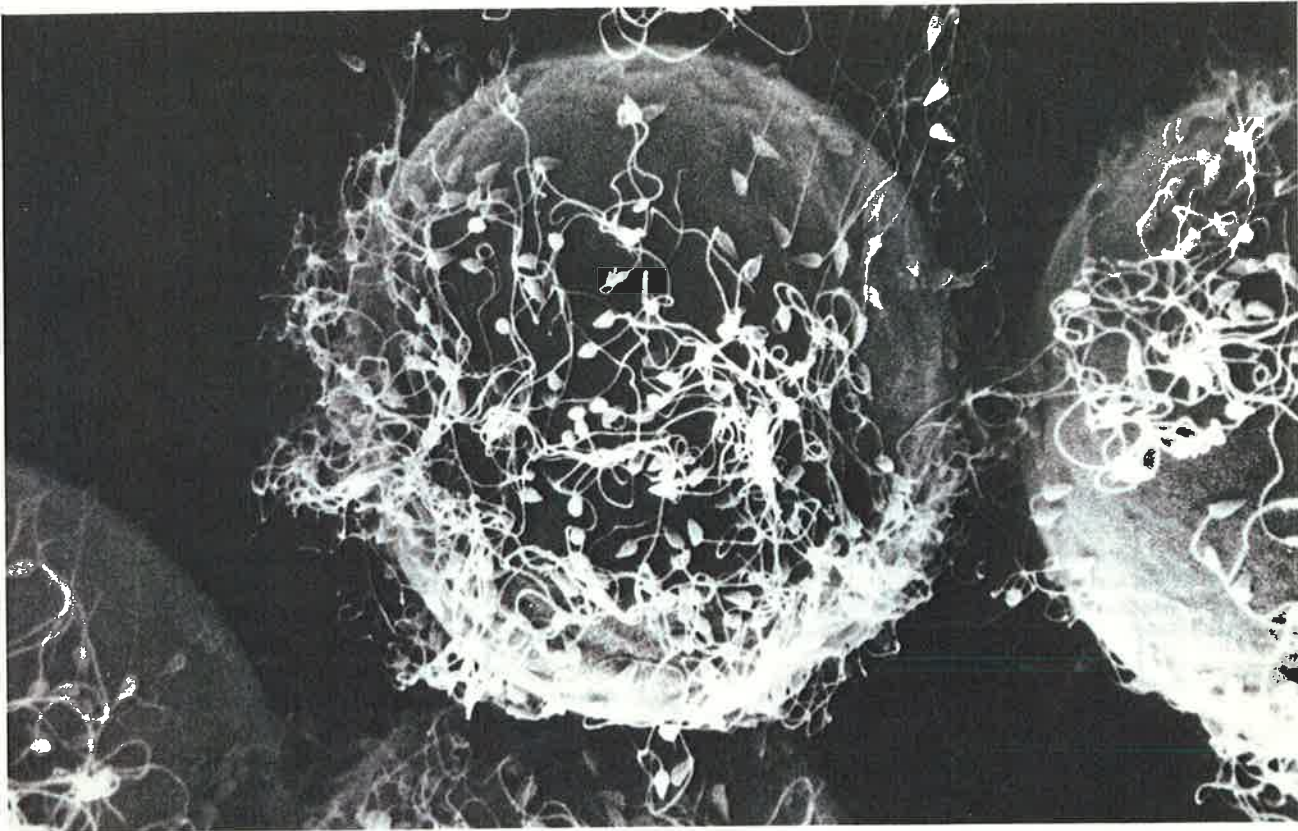
### Fertilization

One of the most exciting areas of research in developmental biology today is the study of fertilization. Although it is one of the oldest subjects of research in biology, the major underlying mechanisms have eluded researchers. Currently, intensive biochemical studies have begun to provide a description of the process at the molecular level.

The first description of sperm cells was made in 1677 when Anton van Leeuwenhoek invented the microscope and examined a sample of his own semen. He and other early microscopists interpreted what they observed as encapsulated miniature humans (homunculi), which could be implanted in a female for an incubation period prior to birth. It was not until 1875 that the fusion of sperm cells to eggs and subsequent fertilization were observed in starfish by the Swiss biologist, Herman Fol. Fertilization research often has used marine invertebrates as experimental subjects, mainly because fertilization is external, occurring in seawater, thereby making the whole process experimentally manipulable.

Although many questions still exist, the process in general occurs in a series of sequential and interrelated steps as follows: The sperm is activated through interaction with the egg, contact is made, and the tip of the sperm breaks down (acrosome reaction). Very rapidly (less than 10

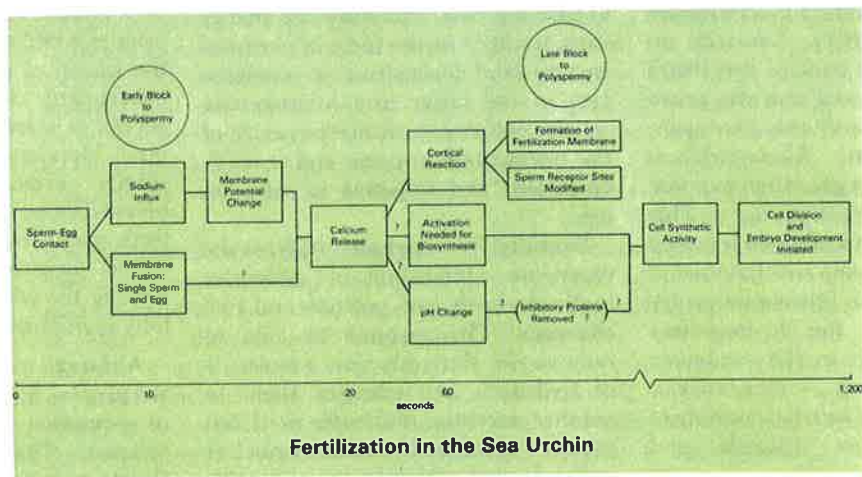




**Initial contact.** Only one of the thousands of sperm in contact with the outer coat (vitelline layer) of the sea urchin egg penetrates to complete fertilization. (Scanning electron micrograph by Mia Tegner while a graduate student in David Epel's laboratory. Magnification: 1500)

seconds) egg and sperm membranes fuse, calcium increases in the egg, further interaction of other sperm and the egg (polyspermy) is blocked, egg metabolism is initiated, the sperm nucleus is transported to the egg nucleus, cell division occurs, and development of the embryo begins.

Current work centers on cell surface phenomena and the functioning of ions (for example, calcium) as triggers for further development of the embryo. This research largely has explained how polyspermy is blocked. The major body of current work on elucidating the early events in fertilization has come from the laboratories of David Epel at Scripps Institution of Oceanography of the University of California, San Diego, and the Hopkins Marine Laboratory at Stanford. Other



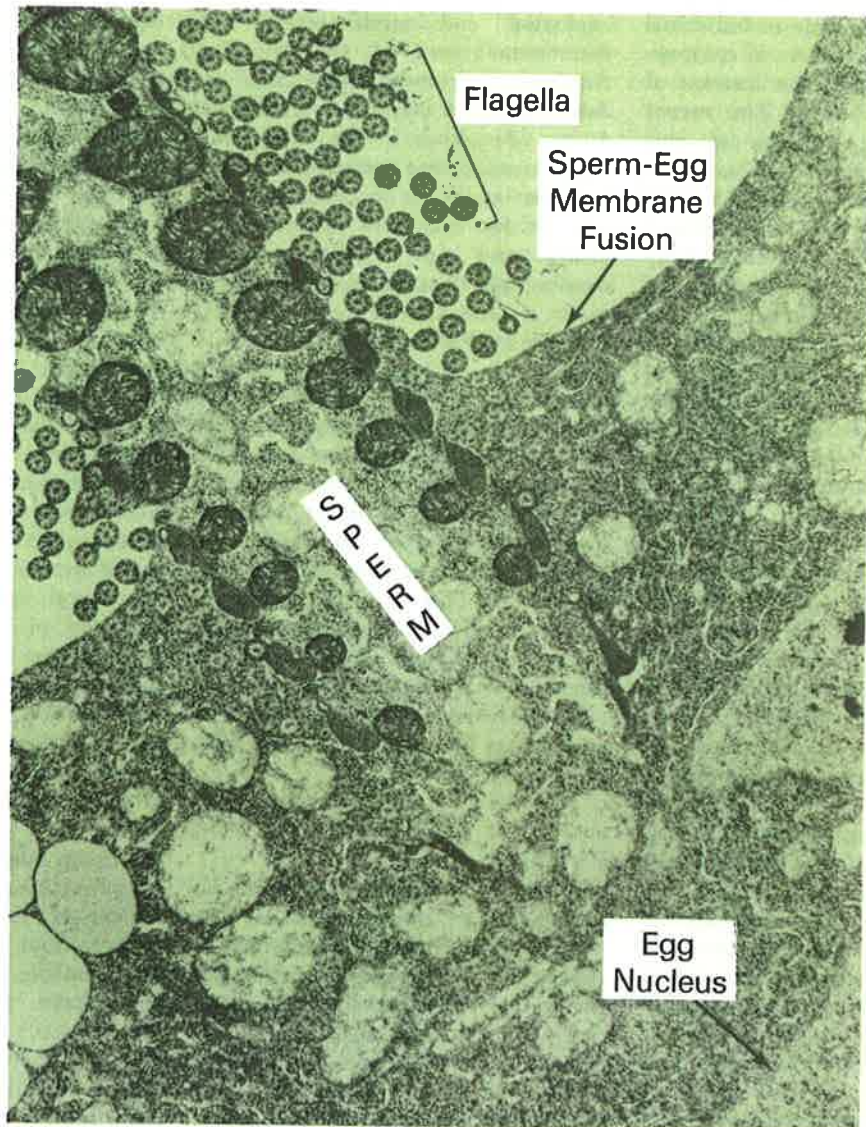
**Sea urchin fertilization.** This diagram summarizes current knowledge about the events of fertilization, with question marks indicating hypothetical relations among known changes. The time from initial sperm contact with the egg to the first cell division is approximately 20 minutes.



work in this area is being done in the laboratories of Edward Carroll, University of California, Riverside; Richard Steinhardt, University of California, Berkeley; Meredith Gould-Somero, University of California, San Diego; and Herbert Schuel, State University of New York at Buffalo. They and their associates have established that the block to polyspermy involves an initial rapid change in membrane potential and is mediated by calcium and other ions. Enzymes released from egg cytoplasm storage sites (cortical reaction) cleave the egg surface membrane and remove sperm binding sites.

The nature of divalent cation regulation of all parts of the fertilization process is of considerable interest and has been postulated to be a universal trigger for activating cell metabolism. The initial rise in calcium in fertilized eggs was demonstrated in Steinhardt's laboratory at Berkeley. By injecting fertilized and unfertilized sea urchin eggs with the luminescent protein aequorin, which emits light only in the presence of calcium, the rise in calcium in fertilized eggs was detected visually.

Research on fertilization in plants is also under way. External fertilization of the water fern, *Marsilea*, was studied by Diana Myles while working with William Jensen at the University of California, Berkeley. As in animals, sperm and egg membranes fuse, and a block to polyspermy occurs. Jensen is studying fertilization of flowering plants *in vivo* and *in vitro* and has evidence that here, too, calcium may be important.



**Membrane fusion.** The multiflagellated sperm of the fern *Marsilea* penetrates the egg following fusion of the plasma membranes. (Transmission electron micrograph by Diana Myles while a graduate student in William Jensen's laboratory. Magnification: 1500)

## Behavioral and Neural Sciences

Research in the behavioral and neural sciences continues to advance rapidly as increasing numbers of scientists focus attention on complex problems of human and animal behavior.

Changes in the central nervous system long have been known to accompany development and senescence; i.e., to show predictable patterns of growth and decay. Whereas earlier data indicated that the

development of the nervous system was controlled by endogenous processes—those produced within the body—recent evidence indicates that some of these patterns can be altered in directed, orderly ways by modifying the environment.

A reawakening of interest in evolutionary concepts in the field of psychobiology has occurred, with a fuller

appreciation of the role of individual behavior in the processes of environmental selection and the creation of succeeding generations. The recent surge of model building in this burgeoning area, popularly known as "sociobiology," has enabled scientists to predict from ecological conditions such characteristics as optimal group size, the presence or absence of territoriality, the occurrence of solitary or communal living, the type of mating system, food preferences and food habits, and the form of family organizations. Sociobiologists also have generated testable predictions regarding the behavior of one individual toward others within any social organization, depending upon the nature of that organization and the ages, genders, and kinship of the individuals involved.

Considerable progress has been made in understanding the manner in which external "geometric" reality—objects and their movements and spatial relationships—are represented internally in human beings. Evidence indicates that the representation is spatial or geometric, similar to the physical representation. Analysis of the time required for a person to indicate whether two objects have the same shape, regardless of the orientations of the objects depicted, supports the hypothesis that individuals mentally rotate one of the objects until they are congruent. This is a step toward understanding the representation of knowledge in a more global fashion.

Technical advances have substantially increased the productivity of research in anthropology and linguistics. Of major importance in anthropology has been the development of new techniques in archeology for understanding past cultures. In linguistics, the use of specially designed and programmed microcomputers has increased the rate—by as much as eightfold—at which field studies can be conducted and analyzed.

During the past year NSF has

evaluated and implemented two recommendations of the National Academy of Sciences report *Social and Behavioral Science Programs in the National Science Foundation*. The Academy recommended that serious consideration be given to providing major support for institutes for advanced study and for anthropological museums. In the first case, a grant was made to the Center for Advanced Study in the Behavioral Sciences, Palo Alto, Calif., to help support leading behavioral scientists working at the center as well as minorities and young researchers who would not ordinarily be invited to study at the center. In the second case a special report, *Systematic Research Collections in Anthropology: An Irreplaceable National Resource*, was prepared as the outcome of a conference sponsored by the Council for Museum Anthropology, Inc. Based on this report, special attention and resources will be devoted to the preservation and accessibility of the most vital research collections.

### Obesity

Obesity continues to have an adverse effect on the physical and psychological health of millions of Americans. Despite the importance of the problem, the antecedents of obesity are not yet well understood. However, recent findings by behavioral and neural scientists are providing new insights into this continuing social and physical problem.

Research by Judith Rodin and her associates at Yale University, extending the cognitive labeling theory of emotion developed by Stanley Schachter, suggests that a high proportion of overweight people may be more responsive than their normal-weight counterparts to availability and stimulus characteristics of food. It is this greater responsiveness to external cues—not a character flaw or a lack of willpower—that is implicated in overeating. Rodin has identified some of the physiological concomitants of

overresponsiveness. For example, the sight and smell of food in overresponsive individuals triggers the release of insulin into the bloodstream; high levels of insulin are known to lead to increased fat storage and to feelings of hunger. Rodin's current work attempts to clarify the influence of external responsiveness on obesity.

Over the past decade the hypothalamus and limbic forebrain have been implicated in the control of emotional and motivational responses, as well as of obesity and feeding behavior. Recently, Ralph Norgren of Rockefeller University, using modern neuroanatomical techniques, has traced nerves from both the taste sense organs and the viscera into the limbic system. His findings provide an anatomical basis for the neural integration of gustatory and visceral sensory cues with feeding behavior, dietary obesity, and essential hypertension. To date, these pathways have been documented only in rodents, but comparable studies in primates are in progress in order to determine the likelihood of similar connections occurring in humans.

Joel Grinker, also of Rockefeller University, is analyzing the relative contributions of sensory, behavioral, and metabolic factors in the control of food intake. His research, capitalizing on genetically obese and lean strains of animals, assesses differences between normal and disturbed energy balances, differences in feeding patterns and the effects of food restriction, and patterns of recovery from obesity. Parallel studies are being conducted with newborn children. The use of genetic animal models has great potential for identifying key aspects of human obesity.

Intriguing research by John Davis of the University of Illinois shows that high levels of glycerol in the blood and body fluids of rats can cause a decrease in their weight. The amount of circulating glycerol seems to provide information for the brain about the size of fatty tissue and current weight.

Thus, glycerol treatment leads obese rats to reduce their body weight. Evidently, a rise in glycerol level is interpreted by the nervous system as an increase in fatty cell size. Weight-control mechanisms then compensate, reducing body weight. Other experiments involving compounds that either suppress or stimulate food intake, such as insulin, also implicate glycerol levels, which are appropriately reduced or increased by these compounds.

### The New Archeology

The "New Archeology" has refocused studies of prehistory from narrow delineations in time and space to increased emphasis on the determination of settlement patterns, exchange and formal trade networks, social organization, occupational hierarchies, the relationship between man and his environment, and changes in this relationship. Archeologists thus increasingly have cast themselves as a special kind of social anthropologist whose subjects cannot be observed directly.

One approach to breathing life into the past as revealed by potsherds, animal bones, stone tools, and the like involves observation of living peoples. This technique enables the investigator to observe variability in both behavior and material culture simultaneously. The ethnographic present—that is, observation of living populations—provides a controlled context, something which by definition is absent in an archeological site. As the present can be used to elucidate the past, likewise, archeological data may illuminate the ethnographic present, placing observed societies in the more meaningful perspective provided by an extended time frame. Several research projects have furthered the development of these approaches that span the boundary between archeology and ethnography—the past and the present.

Ethnographic fieldwork among the

Kalinga, a tribal people of the mountains of northern Luzon in the Philippines, shows that subtle variations in the form and design of pottery, traditionally made at home, reflect aspects of residence, learning frameworks, and composition of the task group.

Until recently, aborigines in the western desert of Australia held to a traditional hunting and gathering way of life. Studies of their social organization and subsistence techniques have provided invaluable clues in the interpretation of archeological remains from a deeply stratified rock shelter located within this region. Examination of aborigines' use and disposal of stone tools has provided models of general use in the study of ancient paleolithic peoples.

The Bushmen hunter-gatherers of the Kalahari desert have been studied

from a similar point of view. In the controlled context of the ethnographic present, it was possible, for example, to note family arrangement within a campsite, map the debris that accumulated during occupation, and devise and test techniques that permit derivation of social facts from observed remains. Bushmen still hunt game from blinds constructed near temporary water points. Studies of both the contemporary predators and prey provide direct clues in the interpretation of prehistoric artifacts, some over a million years in age.

In both southern and eastern Africa, investigators have observed in detail the process by which animal bones are interred. Since animal remains constitute one of the major categories of material from both archeological sites and locations where fossil hominids are recovered, understanding the



**Reconstructing past societies.** As part of a research project relating contemporary living patterns to the "archeological" records they produce, Kalahari Bushmen are employed to sift for artifacts at a campsite they occupied several decades before. Information gleaned from such investigations permits more accurate interpretations of excavated prehistoric sites.



processes involved in their selective preservation or destruction over time is essential in interpreting archeological data. The examination of present-day butchering, cooking, and disposal

techniques practiced by different cultures and the followup studies that track the course of discarded bones over periods of time provide a valuable means to this end.

supported study as prime natural sites representative of the Nation's diverse array of ecosystem types. A primary criterion for support of an identified facility is the strength of the ongoing research program.

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## Environmental Biology

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Research in environmental biology increases understanding of the systematic, evolutionary, and ecological relationships of plants, animals, and microbes. Hierarchical schemes of classification are continually improved by supplementing traditional approaches with techniques and insights from other disciplines. For some evolutionary biologists, new biochemical techniques have initiated a novel series of studies into the rates of change of DNA and protein molecules. Advances in the systematics of tropical biota, on the other hand, have profited from the establishment of new formats for international cooperation as well as from technological improvements such as remote sensing, a demonstrably potent tool for vegetation analysis of large regions.

For the past several years, evolution-oriented research in population genetics and research in population and physiological ecology have been converging. Many projects focus on the patterns of genetic variability within a population with respect to the population's ecological, behavioral, metabolic, and physiological attributes. To a considerable degree, this converging trend is a consequence of the availability of the analytical technique of electrophoresis as a method for estimating, at the molecular level, the genetic variability within populations of a wide array of organisms hitherto unamenable to genetic analysis. A new program was established at NSF to provide uniform review for these proposals. This action should serve to strengthen this sub-

discipline since each proposal will be scrutinized by a larger group of experts representing several subspecialties.

Community ecology persists as the core effort in NSF's ecology program, which supports research in terrestrial and inland water habitats. The research interest remains high in studies of interspecific interactions—such as plant-herbivore, flowering plant-pollinator, prey-predator, and symbiotic interactions. Increasing attention is paid to the communitywide consequences of these interactions.

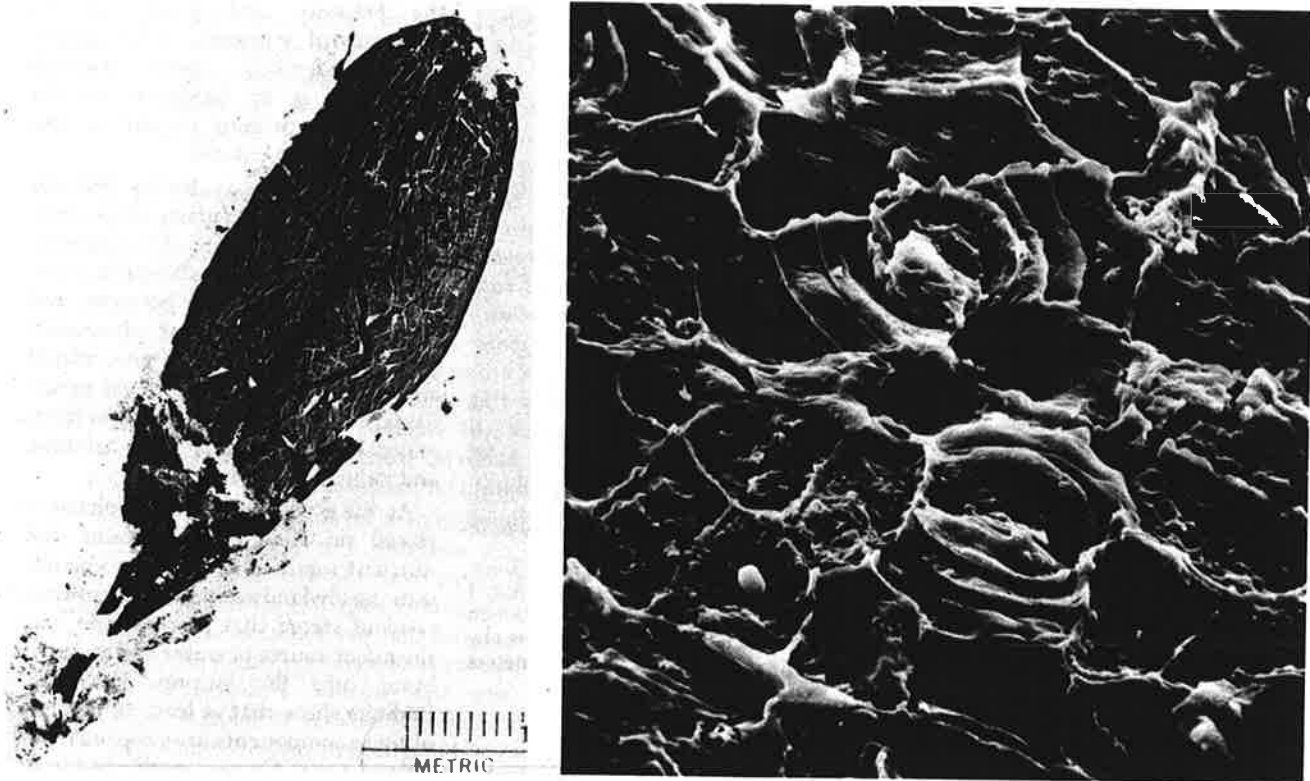
Seven of the more than two dozen projected volumes in the Synthesis Series of the International Biological Program (IBP) are in print. While the large, integrated projects initially supported under the aegis of the IBP have reached the terminal synthesis stage, "second-generation" projects on other areas continue—for example, on the Alaskan taiga and several wetland ecosystems such as the Okefenokee Swamp. Interest has quickened in the cycling of elements in the global ecosystem. This biogeochemical research focuses on the role of terrestrial vegetation in affecting the carbon dioxide content of the atmosphere—a topic of concern because an increase in atmospheric carbon dioxide over the past decades is clearly evident.

The scope of the program for biological research facilities includes new support for field research facilities. The initial recipients of awards were selected from among those identified in a recent NSF-

## Paleobiology

In 1977 the Alan T. Waterman Award, the Foundation's special recognition of young scientists, was presented to J. William Schopf, an investigator supported by the systematic biology program. The award consists of a medal of recognition and a prize of up to \$50,000 per year for 3 years to be used for research or advanced study. Schopf, a professor of geology and geophysics at the University of California, Los Angeles, has devoted his career to the study of the evolution of early life forms and has identified three problem areas for continuing research: (1) geologic evidence relating to the origin of the earliest living systems; (2) atmospheric evolution as it relates to the development of an oxygen-rich atmosphere; and (3) the correlation of microfossils with geologic strata of the Precambrian period.

Recent research by David Dilcher of Indiana University on the origin and early evolution of the flowering plants (the angiosperms) has shaken many established theories on relationships of early angiosperm groups. His studies on floras from Kansas and the southeastern United States in the Cretaceous period (about 100 million years before present—m.y.b.p.) and Eocene epoch (about 50 m.y.b.p.) have benefited from careful use of modern techniques, including scanning electron microscopy of stomatal and other leaf features, plus special clearing and staining techniques of the leaves to reveal cuticular and vein patterns. The results show that nearly 80 percent of the past identifications, based primarily upon gross leaf morphology, are in serious error. Dilcher's studies not only provide a sounder basis for



**Cretaceous leaves.** The fossil leaf on the left, found in Kansas, shows the burrow of a leaf miner, the earliest known record of such insect behavior. On the right is a scanning electron micrograph of a stomatal complex—that part of a leaf containing pores which permit gaseous exchange—of a similarly aged leaf.

techniques for identifying fossil angiosperms but contribute much to revealing the types of flowers existing in Eocene time. His research indicates that both wind- and insect-pollinated flowering plants, representing two different reproductive systems, existed during the Eocene. This is especially important because the modern systems of classifying the flowering plants are based principally on reproductive structures.

New localities of fossil-bearing rocks often lead to a greater appreciation of the diversity of ancient life. Occasional discoveries provide exceptional opportunities for paleontological insights. The Paleozoic Bear Gulch Limestone of central Montana, for example, is yielding a spectacular assemblage of bony and sharklike fishes plus a broad diversity of associated invertebrates,

all magnificently preserved. The vertebrate fossils from the Mississippian (about 330 m.y.b.p.) rock unit are being studied by Richard Lund of Adelphi University. In addition to excellent detail of hard parts, the specimens also include rarely encountered outlines of the skin and soft anatomy. Excavation has yielded hundreds of specimens of many species from this largest assemblage ever found in Paleozoic rocks.

Results of research in other disciplines regularly are being applied to paleobiological investigations. For example, work in neurophysiology has demonstrated that brain fissures delimit functional areas of the cerebral cortex. Thus, it is now possible to describe and make functional interpretations of the actual course of brain evolution by comparing fossil en-

docasts (internal casts of skulls). Leonard Radinsky of the University of Chicago is using endocasts of the braincases of extinct Cenozoic ungulates (hoofed mammals) and comparing them with those of their contemporary predators in his investigations of coevolution between phylogenetically unrelated but ecologically dependent groups of extinct mammals. Radinsky's study, which spans some 58 million years of geologic time, explores brain evolution in North American-Eurasian artiodactyls (cattle and allies) and perissodactyls (horses and allies) relative to each other and to that in their major predators, the Carnivora. Although much of the neurological fine detail that actually may have been involved is not recognizable in endocasts, preliminary results show that in the



**330 m.y.b.p.** From the rich assemblage of fossils being found in Montana's Bear Gulch Limestone is this female *Echinochimaera meltoni*, the earliest known relative of today's rattfish—fish with a cartilaginous skeleton, but not closely related either to sharks, which have a similar skeleton, or to the more familiar bony fishes. The sex can be determined by the shape of the dorsal fin spine. The rounded portion of the body is about 35 millimeters long. (Photo by Leon Serchuk)

Eocene (about 54 to 38 m.y.b.p.) the perissodactyls were in advance of the artiodactyls in terms of expansion of the neocortex, particularly the frontal lobe. Radinsky suggests that this may have resulted from the earlier specialization of the feeding apparatus of the perissodactyls; i.e., more sensitive lips and tongue. By the Oligocene epoch (about 38 to 25 m.y.b.p.), however, the artiodactyls "caught up" with the perissodactyls in relative brain size and then surpassed them in overall adaptive success.

### Okfenokee Swamp Ecosystem

The primary objective of ecosystem studies is to provide a better understanding of the structure and function of complex assemblages of biological and physical landscape units. Research on a given ecosystem may span the full array of system components, from cellular to population levels. Such studies are characterized

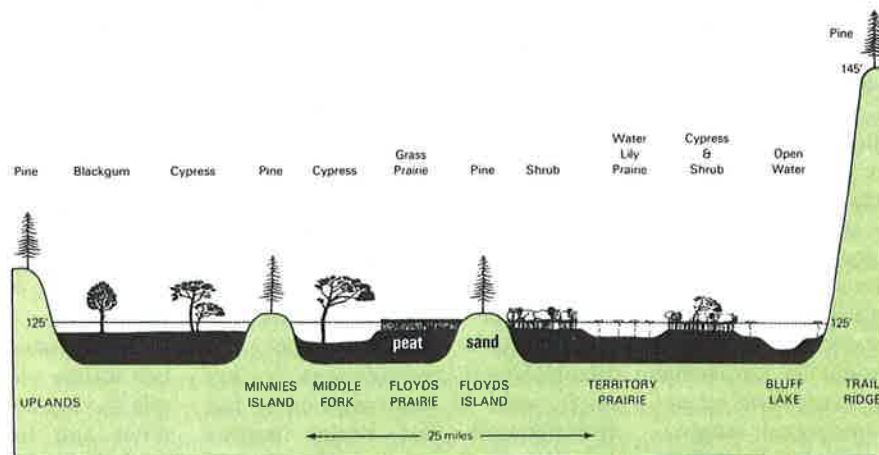
by a multidisciplinary team of scientists seeking to integrate their findings toward the common goal of defining

the behavior and predicting the responses of a system. A significant effort addressing these research challenges is in progress in the Okfenokee Swamp region of the southern United States.

The research team, led by Bernard C. Patten at the University of Georgia, is addressing a number of hypotheses related to the swamp structure, basic vegetation successional patterns, and the effect on nutrient dynamics. Studies are organized and interrelated around four hierarchical level structures of the swamp: the ecosystem, major habitats, transitional habitats, and habitat components.

At the ecosystem level, emphasis is placed on studying the water and nutrient input from the pine uplands into the lowland swamp. Conventional wisdom stated that precipitation was the major source of water and nutrient input into the swamp. However, findings show that at least 50 percent of these components are supplied from upland areas. Consequently, resource management practices on these contributing areas necessarily affect

EAST-WEST TRANSECT OF OKFENOKEE SWAMP



**Structure of a swamp.** This east-west section across the width of the Okfenokee Swamp in southern Georgia shows the typical mixture of local environments and vegetation types found there. (The vertical scale is exaggerated; total relief is only 40 feet.) Current research aimed at understanding the swamp ecosystem will have a bearing on compatible land use planning for adjoining areas.



swamp maintenance. Another study involves a reevaluation of the swamp's origin. The basin was thought to be of marine origin, but radiocarbon dating of peat and the lack of fossils suggest the marine theory is unlikely. Alternative theories of river or lake origin are being investigated.

Habitat research focuses on nutrient regeneration and nitrification processes for the most conspicuous habitats: black gum and cypress bays (forests), shrub swamps, prairies, and pine islands. Prior to this research, pure cypress forest was thought to be a dominant vegetation type in the Okefenokee. The area now is known to contain 39 percent mixed hardwood-swamp forest, 34 percent swamp shrub, 21 percent prairies (including open water), and only 6 percent pure cypress.

The Okefenokee contains unique transitional habitats, the most important being floating peat islands. They are thought to form when open water areas are colonized by aquatic macrophytes or large plants. As peat accumulates or as the water level decreases, the peaty soil rises above the surrounding prairie surface, and the floating peat mass detaches from the bottom. Subsequently, "tree houses" consisting of terrestrial-oriented plants are formed. With additional peat accumulation, succession (the sequence in which plant species follow one another in an area) proceeds toward cypress swamps and thence to bay forest or mixed hardwood swamp. Formation of peat islands also may be an important step in nutrient regeneration processes.

A major habitat component selected for study is the subsystem of algae-bladderwort clumps submerged in prairie waters. These multispecies subsystems are believed to be important in productivity and nutrient cycling. A microecosystem of interest to microbiologists involves the substantial production of methane gas, a phenomenon not expected in the acidic

anaerobic swamp environment. An unknown bacterium may be responsible.

The examination of succession and nutrient dynamics at the four hierarchical levels will be valuable in evaluating the impacts of adjacent land management practices, such as

channelization of forest lands, on the Okefenokee.

### Microbial Ecology

Microbial ecology, which examines the complex of microbial organisms and their activities in natural eco-



**Microflora.** Studies at Michigan State University are concentrating on the types and densities of microbes living within the digestive tracts of aquatic insects and their role in breaking down organic materials entering the water environment. Shown here are scanning electron micrographs of a variety of bacteria in insect larva hindguts, magnified several thousand times. (Photos by Michael Klug/MSU)

systems, is a relatively new entrant into ecology despite long-term recognition of the essential function of decomposition in ecosystems. An obvious deterrent to the study of microbial ecology is that microbial systems are extremely heterogeneous, and the individual organisms are minute. Studies of individual microorganisms in nature have been limited to date because of inadequate methods. E. L. Schmidt of the University of Minnesota, however, recently has made a major contribution in this area. He used fluorescent antibody (FA) techniques to investigate the distribution and metabolism of previously cultured organisms in natural ecosystems, such as soils. Specifically, he is using FA techniques for detailed study of the autecology (ecology dealing with individual kinds of organisms) of chemosynthetic nitrifying bacteria in relation to nitrogen. The principal importance of the work, however, is that with the FA technique, microorganisms can be seen and identified simultaneously.

Nitrogen is the mineral nutrient that most often limits agricultural plant production. In natural ecosystems nitrogen in the soil is produced from diverse sources. Several current studies are examining microorganisms and legumes other than the familiar *Nitrobacter*, *Rhizobium*, and legume species usually associated with the nitrogen cycle. John Torrey and John Tjepkema at Harvard University are investigating nitrogen fixation in nonlegumes with root nodules formed by an actinomycete-type of endophyte and also in less familiar plants that lack nodules. The researchers are also investigating the infection process and nodule formation in *Casuarina cunninghamiana*, a tropical tree. A number of nodulated nonlegumes (*Alnus*-alder and *Myrica*) are known to "fix" or trap atmospheric nitrogen on a symbiotic basis. Douglas Eveleigh of Rutgers University is studying nitrogen fixation by an unknown bacterium associated with a nonleguminous

plant, bayberry (*Myrica pennsylvanica*).

An important part of the decomposition of the largely external organic input into aquatic systems, particularly streams, is accomplished by aquatic insects. Little is known of the role of the microflora occupying the gut of these insects. They may operate similarly to the gut floras of ruminant animals or terrestrial insects, such as termites, in the digestion of plant material. Kenneth Cummins and Michael Klug of Michigan State University seek to demonstrate the presence and distribution of microorganisms in the gut of aquatic insects using scanning electron microscopy to illustrate the types and density of the microbial flora. Initial studies on an aquatic larvae of *Tipula abdominalis* demonstrated that its gut tract, particularly the hind gut, was a "jungle" of microbes. The flora is entirely bacterial, either free in the

cavity of the gut or attached to the inner gut wall.

Subsequent studies by A. K. Meitz at Michigan State University of 26 species of aquatic invertebrates, mostly insect larvae, revealed the widespread occurrence of a gut microbiota. The presence or absence of a gut microbiota correlates with the food habits of the insects. Detritivorous insects, feeding on a fibrous diet, have a distinctive microbiota. Those feeding on more nutritious diets, such as algae, have a sparse microbiota or none. Predators having sucking or piercing mouthparts lack a gut microbiota, while those that ingest prey have one. The precise role, if any, that the gut microbiota plays in the nutrition of these insects is unknown, but the prolific populations of bacteria in insect guts have a role in processing the external organic material of stream ecosystems.

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## Social Sciences

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Social science research, by increasing our understanding of social institutions and social events, informs us of the probable societal consequences of individual and collective actions. The goal of basic social science research is not simply to know what is happening, but to understand how societies "work." The complexity of social and economic systems, the relevance of many variables influencing how such systems operate, and the difficulties entailed in obtaining descriptive data in sufficient detail and scope to permit informative analysis make this a long-range and challenging task. Nonetheless, modest but noteworthy progress toward more comprehensive understanding of social institutions and social systems is being made.

Underlying recent advances in social science understanding are some ongo-

ing developments that NSF seeks to facilitate and encourage. The most important of these are the following:

*Knowledge transfer across disciplinary boundaries.* The most notable example of a surge of cross-disciplinary activity is the area of "political economy"—a traditional label with new meaning. It entails the use of economic reasoning in the analysis of nonmarket decision-making, including political decisions. It also includes the incorporation of political variables in macroeconomic models and the use of economic variables in accounting for macropolitical events. Such studies are being accorded high priority because they constitute strong, productive research efforts that increase our understanding of a wide range of social phenomena.

*Improving data resources.* There is a growing need for more comprehensive

would be the case if the present Social Security System remains in effect.

Being covered by Social Security is like owning an annuity; i.e., a claim on future annual payments when the individual reaches age 65. Accordingly, it is instructive, Feldstein argues, to use the total value of these Social Security annuities as an estimate of the likely effect of Social Security on the total private stock of real wealth. He estimates the 1971 value of this Social Security "wealth" at \$2 trillion and the private wealth of households, exclusive of Social Security, at about \$3 trillion. His calculations suggest that Social Security may have reduced the stock of private wealth by about 40 percent—i.e., from \$5 trillion of wealth that would exist without Social Security to the \$3 trillion that currently exists. Social Security wealth nearly tripled from 1955 to 1971, rising from 114 percent of the gross national product to 198 percent in 16 years. The impact on capital accumulation is thus increasingly important.

While not definitive, Feldstein's present findings are nevertheless sufficient to call in question basic features of the Social Security program and to suggest new directions for public policy. In concentrating on the problem of reduced capital accumulation, he emphasizes that it is not due to Social Security as such but rather to the "pay-as-you-go" nature of our existing system. Under this system there is no real investment of Social Security tax payments and therefore no interest is earned on these compulsory contributions. Social Security tax receipts are simply paid out as concurrent benefits and are not accumulated. The establishment of a Social Security Fund, Feldstein argues, would be a preferable arrangement since it would increase capital accumulation and thereby augment the level of real income. Feldstein assumes that there would be no dearth of opportunities for profitable investment and, consequently, the earnings

of the fund should be comparable to the average 12-percent return on corporate investment.

### Changes in Residential Segregation

Aggregated data describing short-term national trends lend themselves all too readily to facile interpretation and misleading conclusions based on common knowledge of other events. In the important area of segregation, for example, studies based on mid-decade censuses of large U.S. cities indicate that residential segregation *increased* from 1960 to 1965. Other research based on 1960 and 1970 Census data indicates that segregation *decreased* during the decade. There have been differing interpretations of these two findings. Was a trend toward increased segregation reversed during the last half of the decade or are the results a statistical artifact?

W. Clark Roof of the University of Massachusetts and Thomas L. Van Valey of the University of Virginia are endeavoring to resolve this question. Roof and Van Valey have found that, while the average degree of segregation was indeed lower for the 237 Standard Metropolitan Statistical Areas (SMSA's) that the Bureau of the Census identified in 1970 than for the 137 SMSA's identified in 1960, there was little overall change for the 137 SMSA's in the original sample. The 100 new SMSA's added in 1970 accounted for the reduction in the overall level of segregation. Cities and their surrounding areas are classified as SMSA's in accordance with criteria of size and metropolitan development; hence, the inclusion of 100 new SMSA's in the 1970 Census classification represents a real increase in the metropolitan population. Since nearly half of these new SMSA's had segregation indexes lower than the lowest index in 1960, the average level of residential segregation in metropolitan areas did decrease from 1960 to 1970.

However, this does not imply a decrease in segregation in the older and larger SMSA's. The lower average segregation in 1970 SMSA's than in 1960 resulted primarily from interregional population redistribution and not from residential shifts within cities.

The multiple and interrelated trends from 1960 to 1970 may be summarized as follows:

- Metropolitan areas with high levels of segregation in 1960 had higher levels of segregation in 1970. There was a redistribution of the White population to the suburbs and to other regions while the Black population grew and concentrated in the city core.
- Metropolitan areas with low or moderate levels of segregation in 1960 remained at about the same level of segregation in 1970. While the populations of these cities did not remain fixed in size over the decade, the net effect of movement in and out of the city and of movement within the metropolitan areas left the degree of segregation largely unchanged.
- White Americans in metropolitan areas were more likely in 1970 than in 1960 to be living near a few Black individuals or families but less likely to be living in areas where Blacks were more than a small minority of the population. This is primarily a result of the redistribution of the urban White population from large cities with large, highly segregated, Black populations to smaller cities with less segregated, but also proportionately much smaller, Black populations.
- Black Americans were more likely in 1970 than in 1960 to be

data designed specifically for analytic purposes and for improving the reliability and validity of social science data. Methodological advances during the past decade have increased the capability of the national social science research community to develop such data resources. Two efforts presently being supported by NSF are the National Election Studies and developments in social indicators. Investment in these resources has a delayed payoff. The full potential of the data produced cannot be realized immediately; it must await the general accessibility of the resource and, for some purposes, the accumulation of data over a sufficient period of time to permit the exploration of trends and the examination of relationships before and after critical changes in societal conditions.

*International collaboration in research.* A substantial part of contemporary social science knowledge is based on studies developed within individual nations during particular periods of time. Because of this restriction, many social science conclusions have not been tested widely. An efficient way to increase the scope of social science findings is to collaborate with scientists in other countries. International collaboration is also advantageous because it offers positive opportunities for international understanding, cross-national cooperation, and mutual intellectual stimulation. The groundwork for effective collaboration is being built through international conferences and workshops, primarily with Western Europe.

The two projects summarized below illustrate some of these potentials. The study of social security and savings exemplifies the use of rational decisionmaking models in economics; adaptations of such models are now being used in other social science disciplines. The study of changes in the residential segregation of blacks and whites in large American cities draws on one of the most commonly used

data sources for social science research, the U.S. Census. The basic focus of each study readily lends itself to productive cross-national comparison and analysis. Both concentrate on topics of current national interest that have received extensive popular treatment as well as scientific attention, and both illustrate the complex interaction of multiple factors in events of far-reaching social significance.

### The Impact of Social Security

The vast size and continuing growth of the Social Security program has major effects on the overall performance of the Nation's economy. A perennial concern, currently much to the fore, is the problem of financing the system. However, the most important long-term impact of the program, according to recent studies by Martin Feldstein of Harvard University, is the substantial reduction it causes in the Nation's rate of savings. This reduction in savings means less capital accumulation and therefore a lower level of productivity and national income.

Feldstein bases his work on the life-cycle model of savings behavior developed by Franco Modigliani of the Massachusetts Institute of Technology and Milton Friedman of the University of Chicago in the 1950's. This theory holds that the short-run variations in the savings rate can be understood as the result of households adding to their savings to the degree that their current income exceeds their perception of permanent income and drawing from savings when current income falls below the perceived permanent income rate.

In Feldstein's life-cycle model, the system of social insurance is critical in determining the timing of retirement. If the retirement period is fixed, as the earlier Modigliani model assumes, the

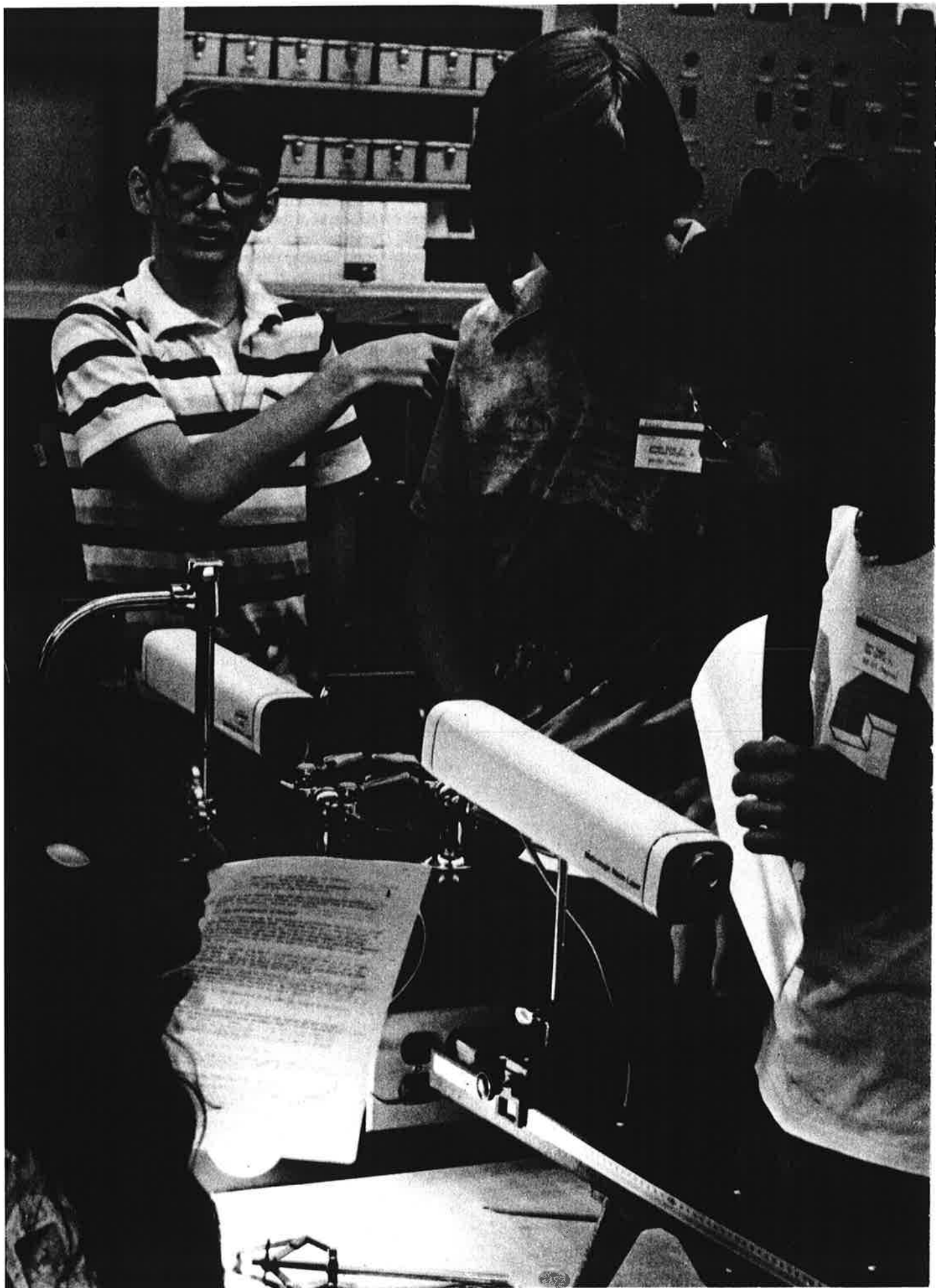
introduction of Social Security retirement benefits will reduce savings during the working years by an amount that leaves planned consumption during retirement unchanged. An individual with an income, say, of \$20,000 who, in the absence of Social Security, wants to save 10 percent of his income (or \$2,000), finds that Social Security now involves compulsory savings of about \$1,800. He, therefore, need only save an additional \$200 instead of \$2,000. However, in Feldstein's life-cycle model there is a second effect of Social Security that would tend to increase personal saving. By providing payments to older people who retire, Social Security induces the aged to reduce their working years. The resulting increase in the period of retirement should induce additional saving. The net effect of Social Security on the savings of the nonelderly consequently is indeterminate and depends on the relative strength of the traditional "saving replacement effect" and the new "induced retirement effect."

Initial evidence indicates that the reduction in savings due to the replacement of private wealth by Social Security "wealth" is much greater than the effect on savings of induced retirement. In the first direct test of his life-cycle model, Feldstein examined savings behavior in the United States from 1929 to 1971. The statistical estimates indicate that personal saving of households in 1971 was approximately halved by Social Security. This means a reduction in total private saving (including corporate as well as personal saving) of 38 percent. The effect of this reduction on the eventual level of the capital stock depends on the production technology of the economy. Feldstein makes the plausible assumption that the long-run (equilibrium) capital stock is proportional to the savings rate raised to the power 1.5. On this basis the parameter estimates of his time series data imply that U.S. capital stock would eventually be some 60 percent higher than

living in predominantly Black urban areas. This is primarily a result of continued migration of Black Americans from the South into large, highly segregated, central cities of the Northeast and North Central regions coupled with a relatively low rate of movement out of these central cities to their suburbs and to other regions.

The aggregate effect of many decisions about where to live determines the general degree of residential segregation experienced by both Black and White residents of American metropolitan areas. Those decisions pertain not simply to the choice of neighborhood but also to the choice of city and region. During the decade from 1960 to 1970 the overall *change* in the level of residential segregation for

all SMSA's was more influenced by the latter kind of decisions than by the choice of neighborhood within metropolitan areas. During the present decade the same forces that have been contributing to interregional migration and the differential growth rates of cities and city subareas may still be operating, suggesting that residential segregation may continue to increase in the older, larger cities.





# Science Education



Perhaps the most significant factor affecting science education today is the transition within education from a condition of continuing growth to a steady state. The annual increases in kindergarten through 12th grade enrollments that began in 1955 reached their peak in 1971. Since then, enrollments have begun to decline. Enrollments in institutions of higher education are no longer growing rapidly and are expected to peak in the mid-1980's.

One immediate effect of the decline in enrollments is the limiting of new openings for teachers in schools and colleges and a consequent general aging of faculty through "tenuring in." This condition has important implications for both the maintenance of vitality of instruction in the sciences and the advances of scientific knowledge.

Accompanying the steady state situation is a general tightening of the budgets of schools and colleges. This condition is made more severe by sharp rises in noninstructional costs such as energy, construction, and maintenance. As a result, the proportion of the education budget available for instructional materials and equipment and faculty development is declining.

A third important factor affecting the science education system today is a general trend toward open access. Examples of this are the broadening of regular school programs to accom-

modate the needs of a wider variety of students at the precollege level, and open admissions, recruitment of women and minorities, and the growth of adult education in postsecondary education. Added to this is the increased significance of the community college as a supplier of education. All of these factors point to a growing demand for diversification in the education system.

A fourth major condition affecting science education is the increasing significance and pervasiveness of sci-

ence. Science has an immediate impact on the daily lives and employment prospects of all citizens. Current public issues such as control of DNA research, the safety of saccharin, the use of laetrile, pollution controls, etc., have led to a general increase in citizen involvement not only in science issues but also in issues of open government and other areas.

Thus, the current Science Education program activities of the National Science Foundation have shifted from an earlier primary concern with the

**Table 5**  
**Scientific Personnel Improvement**  
**Fiscal Year 1977**

(Dollars in Millions)

	Proposals		Awards		Number of Individuals Supported
	Number	Amount	Number	Amount	
Fellowships and Traineeships .....	6,045	\$ 54.50	664	\$15.33	1,784
Graduate Fellowships .....	4,914	25.95	550	10.80	1,587*
Minority Institutions Graduate Traineeships .....	13	3.72	5	1.00	42
National Needs Traineeships .....	86	10.52	20	2.16	66
National Needs Postdoctoral Fellowships .....	1,032	14.31	89	1.37	89
Student-Oriented Programs .....	1,412	23.26	380	5.54	7,040
Student Science Training .....	388	9.13	147	1.93	5,035
Undergraduate Research Participation .....	746	10.23	169	2.65	1,462
Student-Originated Studies .....	278	3.90	64	.96	543
Minorities, Women, and the Handicapped .....	157	4.57	72	2.00	1,400
Faculty Improvement Programs .....	2,024	49.00	322	8.04	14,266
Pre-College Teacher Development .....	869	25.90	187	4.84	10,747
College Faculty Short Courses .....	55	2.68	16	.98	3,400
Science Faculty Professional Development .....	1,100	20.42	119	2.22	119
<b>Total .....</b>	<b>9,638</b>	<b>\$131.33</b>	<b>1,438</b>	<b>\$30.91</b>	<b>24,490</b>

\* Includes 1,037 continuations of prior year awards.

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

production of scientific manpower to a broadened mission to improve quality and diversity, increase the access of previously unserved groups, and provide a minimum level of under-

standing of science to all citizens. In pursuing this mission, the Foundation's Science Education program supports efforts to improve science instruction in the formal science

education system and also supports activities that utilize informal, out-of-school mechanisms to improve the general public understanding of the interface between science and society.



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**Student Science Training.** Intensive summer programs at local colleges immerse high school students in advanced science instruction. Among the 147 projects in 1977 were these four activities: (1) use of an electron microscope at the University of Iowa to examine the structure of biological specimens; (2) archeological excavation with the Oregon Museum of Science and Industry; (3) use of diffraction techniques and a laser to measure sizes of red blood cells at Ball State University (Muncie, Ind.); and (4) analysis of oil shale at the University of Tennessee at Martin.

## Scientific Personnel Improvement

Programs that support the improvement of scientific personnel provide the Nation with a more effective supply of scientists—a central and traditional responsibility of the Foundation. Student-oriented programs provide experience in scientific activities to a small number of high school and undergraduate students. Another program develops and tests methods to stimulate the participation in science by women, minorities, and the handicapped. At the graduate and postdoctoral levels, the focus is on training highly talented young scientists, with emphasis on training that will prepare them for research and teaching in scientific areas related to national needs. Faculty improvement programs are directed toward improving the quality of science education and furthering basic understanding of science by all citizens through support of programs in all fields of science at all levels.

### Student-Oriented Programs

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

### Student Science Training

Of the 147 projects for 11th and 12th grade secondary school students supported in 1977, 86 were designed

for the educational development of high ability students and 61 were designed for students with demonstrated high potential but limited educational opportunities. These latter projects were targeted for students: (1) with inadequate facilities or instruction; (2) located in the inner cities or in isolated rural areas; and (3) belonging to educationally disadvantaged populations. Four of the 61 were special projects for high school juniors extending through two successive summers, so that active contact could be maintained with the students through the intervening academic year. The projects, which supported 5,039 students, ranged from engineering and engineering design to urban transportation and pollution problems, from genetic biology to utilization of coal reserves, and from statistical decision theory and operations

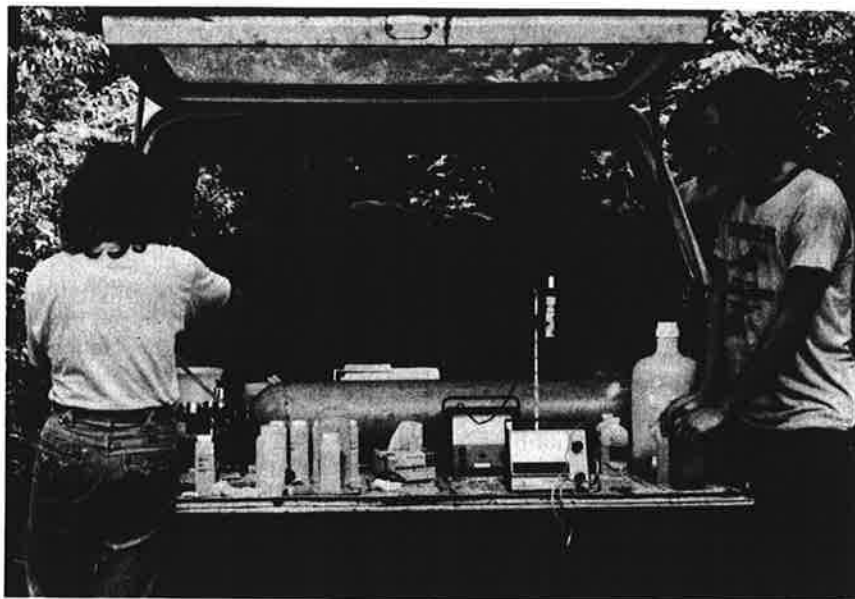
research to remote sensing and environmental problems.

### Undergraduate Research Participation

The undergraduate research participation program provides selected undergraduates with firsthand experience in the research process by enabling them to work full time with university science faculty or industrial scientists. Among the 181 projects for 2,083 undergraduates were archeological field studies on prehistoric mounds; a social survey analysis of minority-governed townships in the South; complex programming languages, software design, and artificial intelligence; and work on industrially related problems.

### Student-Originated Studies

This program encourages students to assume more responsibility for their own learning and to contribute directly to the Nation's research effort on



**Student-Originated Studies.** Members of a project at Wright State University (Dayton, Ohio) take water samples during their study of the effects of strip mining runoff on a natural bog system.

societal problems. In 1977, 64 student-originated studies awards supported projects designed and carried out with minimal faculty supervision by 543 students at 59 colleges and universities. Projects were designed to provide data useful to local governmental agencies in planning or administering public programs, and ranged over an investigation of processes to convert loblolly pine bark components into commercial chemicals; a survey of two rural and two urban counties to answer questions about the transportation needs of the elderly; and a study of the water hyacinth as a purifying agent in a wastewater treatment system, as a potential livestock feed supplement, as a source of methane gas, and as a fertilizer and soil conditioner.

### **Minorities, Women, and the Handicapped in Science**

This program is concerned with developing and testing methods to attract, encourage, and motivate the participation in science by minorities, women, and the handicapped, and with providing special training opportunities beyond those available in existing formal science education programs.

#### **Minorities**

Through the student science training programs, 421 high ability secondary school minority students received special instruction in science and participated in research projects at colleges or universities, while through the undergraduate research participation program 64 minority undergraduate students participated in full-time work with college faculty on research projects.

#### **Women in Science**

The target group for this program was expanded in 1977 through the support of the first phase of a Visiting

Women Scientists project, designed to motivate senior high school women to consider and prepare for careers in science. In addition, 24 career workshops involving approximately 5,800 women students in colleges and universities were carried out in 18 States and the District of Columbia. Ten specially designed educational programs were conducted in seven States to prepare some 290 women with science degrees to enter graduate education or employment in science.

#### **Handicapped**

Fiscal year 1977 was the first year of operation for this program. Of the 11 projects supported, 4 were directed at determining the extent of difficulties faced by physically handicapped students in obtaining an adequate science education and at developing plans for overcoming these difficulties, and 5 focused on experimental training directly involving handicapped students. Participation included 20 high school students who took part in a 4-week summer research project on the accumulation of heavy metals in fish, 50 high school and first-year community college students who participated in a 6-week summer workshop on careers in science, and 30 students who attended a 5-week marine science training program.

#### **Fellowships and Traineeships**

Graduate fellowships and traineeships provide for a continuing flow of a limited number of the most talented students into the Nation's scientific personnel pool and strengthen the science programs at the host institutions, while postdoctoral awards make it possible for able young scientists to address scientific problems related to national needs.

#### **Graduate Fellowships**

New 3-year graduate fellowships in science and engineering were awarded

to 550 of the Nation's most promising young science scholars in fiscal year 1977. Another 1,748 applicants in the rigorous national competition for the awards were identified as highly deserving of support, and were accorded honorable mention. Such an identification enables many of the applicants to obtain support from other sources, thus permitting them to join the awardees in undertaking graduate study in the sciences. In all, 4,834 undergraduate science majors submitted applications in this program. The new fellows will be joining some 1,100 previous awardees whose study programs are currently in progress.

#### **Minority Institution Graduate Traineeships**

The minority institution graduate traineeships program first began in 1974. As reinitiated in 1977, the target group consisted of all schools with more than 50 percent aggregate minority enrollment and with more than 100 graduate degrees in science over a 3-year period. As a result of this competition, five awards for graduate traineeships of 3 years' duration were made to target institutions to improve the access of 42 full-time graduate students or their part-time equivalent to careers in science and technology.

#### **National Needs Postdoctoral Fellowships**

Eighty-nine of the ablest young postdoctoral scientists and engineers, selected from among more than a thousand applicants, were awarded fellowships which will enable them to pursue advanced study and research for up to a year on scientific problems related to national needs. Projects supported in 1977 included the development of a technique to systematically analyze medical data, research into better disposal methods for plutonium, the development of a



nonpetroleum resource for certain plastic materials, and research into how deaf persons cope with their handicap.

### Faculty Improvement Programs

Faculty improvement programs are designed to enhance the competence of teachers in order to maintain high quality in the training of students and professionals in the sciences. In 1977, participation in these programs was open to most of the potential field of approximately one million elementary school teachers, 300,000 secondary school science teachers, and 260,000 2- and 4-year college and university science teachers of the United States.

### Pre-College Teacher Development

The pre-college teacher development in science program for the continuing education of elementary and secondary school teachers of science, mathematics, and the social sciences was inaugurated in fiscal year 1977. In addition to improving teachers' knowledge of the subject matter of science, this program develops and maintains communication and cooperation between scientists at colleges and universities and teachers in elementary and secondary schools.

Projects typically involve a group of teachers in full-time summer activity of up to 4 weeks or an instructional activity which meets periodically during the academic year. Approximately 10,750 elementary and secondary school teachers will participate in the 787 projects supported in 1977.

Illustrative of the broad spectrum of projects supported are: a 1-year education program for science teachers to improve their basic understanding and to stimulate their effective teaching at the primary and secondary levels in general science, chemistry, physics, energy-environment, and mathe-



**Handicapped in science.** At a summer program in marine science at Wallops Island, Va., high-ability blind, deaf, and orthopedically handicapped high school seniors have an opportunity to participate in field work aboard research vessels. (Photos by West Virginia University)

matics; intensive 2-week workshops for junior and senior high school science teachers with weak backgrounds in energy resources and related environmental issues; 14 minicourses to serve the needs of high school teachers whose students are slow to average learners, to broaden junior high school teachers' use of local facilities, and to assist elementary teachers in gaining science knowledge; and an intensive 2-week workshop on the teaching of high school psychology, which will feature symposium workshops led by prominent psychologists.

### College Faculty Short Courses

This program introduces faculty to new scientific knowledge and expedites its dissemination in the classroom. Each course is offered at several sites or field centers, with the lecturers moving through a Chautauqua-type circuit from one center to the next. A course consists of two intensive 2-day sessions with an intervening period of several weeks for individual study or work on prepared materials.

Approximately 3,400 college teachers attended 52 different short courses held at 15 field centers across the Nation. The courses dealt with such topics as current developments in plate tectonics and its impact on geological theory, the impact of microcomputers on classroom instruction and research, and the social and scientific impacts of recombinant DNA.

### Science Faculty Professional Development

This program helps college and university science teachers increase their competence in science and thus improve the capability of their science students to meet current employment requirements. In implementing this goal, the Foundation offered awards to

enable 2- and 4-year college science faculty and university faculty teaching primarily at the undergraduate level to pursue research or study for 3 to 12 months at institutions of higher education or in industrial or other non-academic laboratories. Of the 119

awards made in the fields of the mathematical, physical, medical, biological, engineering and social sciences, and in the history and philosophy of science, 58 were for research in industrial or nonacademic laboratories.

## Science Education Resources Improvement

The science education resources improvement programs address the needs of schools, colleges, and universities in strengthening and improving their science education and research training capabilities. During fiscal year 1977 two new programs were added which significantly increased the Foundation's ability to provide institutions with up-to-date instructional materials, equipment, information, and planning capacities. The emphasis in all of these programs is to expand access to participation opportunities to all types of institutions, especially those colleges with limited resources and experience in dealing with NSF.

### Comprehensive Assistance to Undergraduate Science Education (CAUSE)

The major objective of this program is to strengthen the science education capabilities of predominantly undergraduate institutions, departments, or groups of departments. CAUSE addresses the needs of those institutions that have experienced a decline in undergraduate science education standards over the past decade and gives particular attention to institutions heretofore uninvolved in the science education activities of the Foundation.

Recipients of 1977 CAUSE awards

**Table 6**  
**Science Education Resources Improvement**  
**Fiscal Year 1977**

(Dollars in Millions)

	Proposals		Awards	
	Number	Amount	Number	Amount
<b>Comprehensive Assistance to Undergraduate</b>				
Science Education .....	483	\$ 81.70	69	\$10.88
Local Course Improvement .....	750	14.70	129	2.21
Instructional Scientific Equipment .....	1,378	15.30	289	2.97
Information Dissemination .....	98	2.10	17	.39
Minority Institutions Science Improvement .....	89	22.20	38	5.14
Minority Centers for Graduate Education .....	30	1.40	16	.79
Research Initiation and Support .....	155	26.60	30	4.43
Pre-Service Teacher Education .....	9	1.00	9	1.10
Systems, Teacher Centers .....	8	.30	9	.28
<b>Total .....</b>	<b>3,000</b>	<b>\$165.30</b>	<b>606</b>	<b>\$28.19</b>

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



included 19 2-year colleges, 28 4-year non-Ph.D. degree-granting institutions, 16 Ph.D. institutions, and 6 consortia, for a total of 69 awards and \$10.9 million.

Projects reflect each institution's unique efforts to improve undergraduate science education. For example, faculty at Suffolk Community College, N.Y., will reevaluate course offerings and prepare computer modules for the mathematics, physics, chemistry, earth and space sciences, engineering, and economics departments. It is estimated that computer usage in these departments will affect as many as 10,000 students each year. At Colorado College, Colorado Springs, students will complete all science requirements in a newly developed, intensive "Science Semester," in which they will have no other academic commitments. Instruction will cover several science disciplines with 1 month devoted to field studies, the next month to laboratory instruction, and the final month to classroom instruction. A consortium project, including the University of North Carolina (Greensboro), North Carolina A&T State University, and Guilford College, will improve astronomy education on all three campuses by establishing an optical observatory containing a telescope and system whereby beginning astronomy students will have day-to-day contact with the faculty through videotapes. The University of Texas at Arlington will establish a Science Learning Center that will address the laboratory needs of six science departments.

### Undergraduate Instructional Improvement

This program consists of the local course improvement (LOCI) and instructional scientific equipment (ISEP) programs. The common purpose of these small grants programs is to enable institutions to respond rapidly to relatively small-scale undergraduate



**Comprehensive Assistance to Undergraduate Education.** At the College of Marin in California, student assistant Ann Cole and faculty member Gordon Chan develop audiovisual material for use in improving science education (biology) and instructional techniques.

science instructional problems and to enhance science teaching vitality by serving as incentives for science faculty to pursue imaginative ideas in upgrading their instruction.

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

### Local Course Improvement

These awards are aimed mainly at the restructuring of local teaching programs to reflect current scientific and technological developments and improved methods of presentation.

Most projects support an individual or a small group of science faculty members in the design, preparation, and evaluation of new course materials or laboratory experiments. In fiscal year 1977, the program made 129 awards to 123 2- and 4-year colleges and the undergraduate components of universities.

In a LOCI project at the University of Notre Dame a civil engineering course on the design of environmental health control systems will be revised to provide instruction in the design and selection of the equipment necessary for computer operation, control, and monitoring of water and wastewater treatment plants.

At Orange Coast College in California, a LOCI project to improve laboratory courses in biology, marine science, and technology is also expected to provide the local city government with basic data for planning purposes.

The philosophy and science faculties at Tuskegee Institute are using LOCI support to cooperatively develop an interdisciplinary course in the history of the development of science and fundamental concepts of science, as well as the theoretical basis of present-day science.

### **Instructional Scientific Equipment**

These projects are aimed at implementation of improvements in science instruction through the acquisition of new laboratory instruments and other instructional equipment. The objective is to provide relevant, "hands-on" experience for undergraduate students in science and engineering laboratories. In fiscal year 1977, 287 awards were made to 247 institutions. In each case the Foundation grant—a maximum of \$20,000—was matched locally by at least an equal amount of institutional funding.

An ISEP project at Kansas State University involves the purchase of a tristimulus colorimeter, an infrared spectrophotometer, and an ultraviolet-visible spectrophotometer for use in the textile science program. Students will use the equipment to study fiber and fabric composition and the penetration of dyestuffs into fibers.

The objective of an ISEP project at Nashville State Technical Institute is to improve the laboratory of a power systems analysis course by providing a more comprehensive coverage of basic concepts of electric power transmission systems. The engineering faculty at this 2-year college will assemble an electrical power transmission laboratory system using components purchased under the grant.

An ISEP project at Lafayette College in Pennsylvania involves the purchase of an interactive lecture system for the recording and playback of both speech and writing. The physics department and faculty will use the system to

increase the awareness and understanding of physical principles by students in introductory courses.

### **Minority Centers for Graduate Education**

In order to increase the participation in science and engineering careers by minority groups presently underrepresented in these fields, the minority centers for graduate education program was established in 1977 with authorization to support planning and study grants. In keeping with legislative intent, these grants were to be used to determine the need for and feasibility of developing resource centers in science. The centers are to be established at geographically dispersed educational institutions having a substantial minority enrollment and geographically located near minority population centers. Additional institutional criteria to be met included: a demonstrated commitment to encouraging and assisting minority students, researchers, and faculty; an existing or developing capacity to offer doctoral programs in science and engineering; and a willingness to serve as a regional resource in science and engineering for the minority community, to support basic research, and to develop joint educational programs with nearby undergraduate institutions with substantial minority enrollments.

In fiscal year 1977, 16 universities were awarded 6-month planning grants in anticipation of the development of centers. Seven of these awards were in support of proposals submitted by consortia or cooperative arrangements involving several institutions.

### **Minority Institutions Science Improvement Program**

The primary purpose of this program is to effect long-range improvement in science education at institutions with predominantly

minority enrollments. In order to increase the number of minority students graduating with majors in the sciences, mathematics, or engineering and to improve the quality of preparation of these students for graduate work or careers in science, NSF supports science improvement projects at 2- and 4-year postsecondary institutions whose enrollments are predominantly American Indian, Alaskan Native, Black, Mexican American, Puerto Rican, or other ethnic minorities who are underrepresented in science and engineering.

A total of 38 awards, including 33 institutional awards, 1 cooperative grant involving 3 institutions in the Los Angeles Community College District, and 4 design grants to assist institutions without formal planning capabilities in the development of long-range science improvement plans, were made in fiscal year 1977.

Projects involved a variety of strategies for meeting institutional needs. For example, at Medgar Evers College, City University of New York, a mathematics learning laboratory will be established; the American Indian Satellite Community College in Nebraska will outfit a mobile laboratory van manned by science faculty that will serve students at three Indian reservations; and the faculty at Los Angeles City College, East Los Angeles College, and Los Angeles Southwest College will jointly develop computer-assisted instructional programs in science for use with an existing districtwide computer network.

### **Improvement of Pre-College Instruction**

The improvement of pre-college instruction program supports the development and testing of models for more effective pre-service and in-service teacher education and the dissemination of information about recently developed instructional

materials, technologies, practices, and research findings.

In the area of pre-college teacher education, the Foundation has for a number of years supported the development of innovative approaches to the pre-service training of science teachers. Awards made in this (the final) year of the pre-service teacher education program involved a total funding in excess of \$1 million.

Through the support of localized Teachers' Centers, the Foundation continues its efforts to improve the teaching skills of practicing classroom teachers. Renewal grants were made to Teachers' Centers in California and Wisconsin. An evaluation of these and other NSF-funded centers is being conducted through the department of science education at the University of Georgia.

A coordinated attack on complex problems involving State, regional, and urban systems of science education is encouraged by major grants for a few large-scale projects involving several layers in the educational structure. In fiscal year 1977 a final award was made in support of the Oregon System in Mathematics Education project, and two contracts were initiated to assess the impact of the Oregon project and a similar large-scale project in New York City.

The information dissemination for science education program was established during this fiscal year to provide opportunities for school administrators, subject matter specialists, teacher leaders, school board members, and other decision-makers in State and local school systems to obtain information needed to properly examine and evaluate instructional materials and practices. Seventeen awards were made in support of conferences and workshops to provide information on a variety of materials and practices currently available for elementary and secondary school use. Some projects, such as the awards to the National Science Teachers Association, Arizona State

University, and the State University of New York at Stony Brook, provide participants with information on current research results in pre-college science and mathematics education and its potential classroom applications.

Other projects, such as those funded at Ohio State University, the University of California, Santa Barbara, and Chicago State University, are concerned with the dissemination of information on classroom use of such educational technology as the handheld calculator.

### Research Initiation and Support

The research initiation and support (RIAS) program is designed to improve the quality, effectiveness, and efficiency of graduate and postgraduate science education for young scientists and engineers. Program funds assist academic institutions in upgrading their programs for graduate students, postdoctoral appointees, and/or non-tenured faculty members who have earned their highest postgraduate degree within the past 5 years. The support helps provide for those vital aspects of advanced training not covered by research funds. Though RIAS may involve research *per se*, it mainly complements research in the advanced training of young scientists.

The fiscal year 1977 operation followed the basic pattern set down in fiscal year 1976, the program's initial year. Emphasis is on establishing stable institutional program improvements that can be maintained at the expiration of program support and on strong institutional commitment in the form of assuming one-third of the total project costs. Support for specific individuals or other actions tending to increase the numbers of people entering graduate training were specifically discouraged.

The 155 proposals submitted for consideration represent a marked

decrease from the 261 proposals received in the fiscal year 1976 competition. This decrease is attributed largely to the very low percentage of proposals (7.3) that could be supported in fiscal year 1976. Of the 30 awards, totaling more than \$4.3 million, made in fiscal year 1977, 7 went to major research universities, 15 to other doctorate-granting institutions, 6 to institutions whose graduate training is conducted for the most part at the master's level, and 2 to consortia.

The variety of institutional needs and the diversity of types of institutions submitting proposals are reflected in the projects supported. Larger institutions typically focus on one department or disciplinary area. For example, the political science department of Washington University, St. Louis, will develop a broadened curriculum in mathematical modeling of political processes to train graduate students in the effective use of quantitative methods to analyze political and policy processes.

Smaller institutions may concentrate on rather specialized projects. For example, the University of Maine at Orono will improve postgraduate training in migratory fish biology by providing young scientists with opportunities to broaden their backgrounds through workshops and short courses, attendance at scientific meetings, oceanographic cruises, visits to other laboratories, and interaction with outstanding visiting scientist lecturers. RIAS funds will also permit the acquisition of additional facilities and equipment and an increase in the university's teaching collection of fishes.

The University of Wyoming will use its RIAS support to develop an institutional framework for a dynamic program of interdisciplinary academic training and research dealing with some of the critical energy development and environmental impact problems facing the Nation.

An example of an award to cooperating institutions is a grant that

will enable the mathematics departments of Harvey Mudd College and the Claremont Graduate School to initiate a postdoctoral training and

enrichment project that combines "real world" problem-solving experience with traditional academic training in applied mathematics.

## Science Education Development and Research

Science education development and research activities are characterized by their highly exploratory nature and common goal of developing generalizable and transferable new knowledge and products. Target audiences include elementary and secondary school students, college undergraduates and graduates, practicing scientists and engineers who desire to continue their education, and individuals seeking greater science literacy. Projects range from research in learning in science education, through the creation and testing of new instructional materials, to experimentation with novel instructional technologies.

To better coordinate this wide span of effort, a major restructuring of program lines was initiated in fiscal year 1977. Extensive public comment on the new guidelines was solicited and

obtained. Ultimately, the activities of the preexisting programs of pre-college materials development, testing, and evaluation; alternatives in higher education; technological innovation in education; and continuing education for scientists and engineers were combined into a single program—development in science education. At the same time, a separate formal program of research in science education, newly authorized in fiscal year 1977, was introduced.

### Development in Science Education

Fiscal year 1977 was a year of transition for the Foundation's activities in development in science education. Prior to mid-year, proposals dealing with course and curriculum

development for elementary and secondary schools were categorized as pre-college materials development, testing, and evaluation. Similarly, experiments at the baccalaureate and graduate levels were examined as alternatives in higher education, while exploitation of the educational potential of the computer and other technologies was dealt with by technological innovation in education. Finally, continuing education for scientists and engineers concerned itself with the generation of novel and effective means for maintaining the technical currency of older non-academic scientific and engineering personnel. Under this structure, 124 proposals were received and reviewed, and 48 awards were made. Following the announcement of the restructured development program, 429 proposals were received, which resulted in 21 awards. The fiscal year 1977 development awards totaled \$8.7 million.

There is concern in some quarters that attention to science education, at least in the elementary school, may be diminishing as a result of economic stress and an emphasis on "basics." To offset this trend, the Foundation is supporting several projects that investigate alternative or parallel means of delivering science education to precollegiate students. One approach is exemplified by a prototype project directed by Michael E. Browne of the University of Idaho to develop a family-oriented approach to science education for children in kindergarten through eighth grade. In the prototype project, students volunteer to carry out individual science investigations at home. Parental involvement in their children's science education is facilitated by workshops held monthly by the participating teachers. During the workshops, the nature of the studies is outlined and explanations of the phenomena to be observed are given. At the same time, parents receive an "Advisor's Guide" that will assist them in supervising the home-conducted experiments.

**Table 7**  
**Science Education Development and Research**  
**Fiscal Year 1977**

(Dollars in Millions)

	Proposals		Awards	
	Number	Amount	Number	Amount
Research in Science Education .....	237	\$ 23.10	25	\$ 2.35
Development in Science Education .....	475	85.98	72	8.72
Pre-College Materials Development .....	76	13.76	7	1.47
Alternatives in Higher Education .....	304	54.16	55	5.15
Technological Innovations in Education .....	90	17.20	9	2.08
Continuing Education for Scientists and Engineers .....	5	.86	1	.02
<b>Total .....</b>	<b>712</b>	<b>\$109.08</b>	<b>97</b>	<b>\$11.07</b>

SOURCE: Fiscal Year 1979 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Data Tables).

A different approach to informal education is being followed in a Lawrence Hall of Science effort. There are approximately 1,100 small and medium-sized planetaria in this country whose combined programs serve approximately four million school children and adults each year. The present program format is that of an illustrated lecture, but there is evidence that many planetarium educators are seeking an alternative to this format. The Lawrence Hall of Science project, under the direction of Robert Karplus and Alan Friedman, will design and evaluate two models for an alternative format. The models consist of single-visit programs that bring the visitor into active contact with astronomy by using the planetarium as a "laboratory."

Along more traditional lines, classroom teachers experience difficulty in keeping their instruction up-to-date because of the rapid growth of scientific discovery and understanding. Two projects are experimenting with a means for shortening the time required to translate important research results into useful classroom materials. One of these, directed by Edward C. Stoeber of the University of Oklahoma, is preparing 1- to 3-day instructional units based on current scientific research into the processes through which the Earth's crust is changing. In this project, development is carried out at several sites by teams consisting of researchers in crustal evolution, local classroom teachers, and other experts. The other project, which is concerned with chronobiology—the study of biological rhythms—will result in a 2- to 4-week-long minicourse for high school students. Franz Halberg, working at the University of Minnesota, will produce text materials, suggestions for field observations and laboratory experiments, and a guide for teachers of this minicourse.

Many colleges and universities are seeking to diversify their offerings in science education in order to better

meet current needs. Because of differences in the composition of student bodies, a number of different types of model projects that provide alternatives in higher education have been supported. For example, Michael Lowenstein, in anticipation of a demand for solar energy technicians, is heading a cooperative four-institution project to develop a 2-year associate degree program in solar energy technology. Together with Navarro College (the project center), Brevard Community College, Cerro Coso Community College, and Dallas County Community College will develop the necessary courses in solar measurement, energy, economics, conservation, and commercial systems.

Two of the projects for undergraduates pursue a theme of interest in contemporary problems, yet their approaches are distinctive and they are aimed at quite different audiences. In an effort directed by Melba Phillips, the American Association of Physics Teachers will produce a series of 18 modules in physics for use by students who do not have strong backgrounds in mathematics and science. On the other hand, William Schiesser of Lehigh University is preparing a set of mathematical models and computer-based simulations on socioeconomic-technological problems which can be used in fields and disciplines which, traditionally, have been nonquantitative.

Frequently, teachers in very highly specialized fields of science experience difficulties in demonstrating important phenomena to their students. David Green of Harvard University proposes to attack this problem in psychoacoustics—a subject important in experimental psychology, hearing, and perception—by producing a series of audio tapes that have been collected from research laboratories throughout the world. These tape sets will be made available at low cost to interested colleges and universities.

Applications of technological in-

novation to education continue to receive emphasis because the rapid rate of creation of new technologies and the significant reduction in costs of existing ones suggest the potential for improving the quality of science education. For example, workers in computer-based learning systems consider the lack of good quality synthetic speech to be a serious problem. Jonathan Allen, at the Massachusetts Institute of Technology, is preparing a set of algorithms to convert text to speech and the necessary hardware to synthesize the speech at the computer terminal. The objective of the project is to produce an engineering prototype that can be optimized under field conditions. In addition, this work has applicability to the development of a reading machine for the blind.

Developers of videodiscs are presently designing their systems exclusively for the entertainment market. Since a hybrid videodisc-computer system could provide a low-cost, general-purpose instructional device useful to education, Alfred M. Bork of the University of California, Irvine, will organize a small conference to foster cooperation between educators and videodisc developers. Among the expected outcomes are outlines of plans for building an intelligent videodisc system for learning.

A major aspect of the learning process involves a student confronting some problem, developing an answer, and having the answer reviewed and criticized. While this process is carried out in the apprenticeship-like relationship of graduate school, and in independent studies or seminars at the undergraduate level, it has been impractical in large classes. Jerome Woolpy, at Earlham College in Indiana, is investigating how computer conferencing techniques might be used to approximate the benefits of the individualized seminar-type approach in terms of dialogue and cross-critique. Although the system is being tested only in biology and operations

research, if it is successful it can be expected to be useful in many other scientific disciplines.

Continuing education for scientists and engineers operated in a planning mode during fiscal year 1977. Two meetings of experts were held to obtain information and to advise on the most promising directions for Foundation involvement. Background papers have been prepared and analyzed, and a program plan building on these consultations has been developed for fiscal year 1978.

### Research in Science Education

Fiscal year 1977 was the initial year of operation for the research in science education (RISE) program. The program's goals for 1977 were to generate valid information and a rational means for identifying areas in which research in science education is needed, encourage and facilitate more effective use of research results, advance science education through the support of research projects, and encourage exploratory research and the identification of able new researchers through a program of small grants.

Proposals were solicited for critical evaluations of existing work to define the current status of science education research areas. These studies will facilitate the identification of significant research problems and the formulation of possible research agendas. In addition, support was provided for research projects with a high potential for guiding and advancing future science education improvement activities. From among the 233 proposals received in response to the solicitation, 21 awards were made totaling \$2.3 million.

The projects that were supported cover a wide spectrum of areas in science education research. For example, the Center for the Study of Community Colleges is conducting an

examination on a national scale of curriculum and instruction in the sciences in community, junior, and technical colleges. The project, directed by Arthur Cohen, is designed to yield information on the scope, goals, materials, and equipment of courses, as well as on instructional patterns and recent changes in disciplinary emphasis. In a different direction, Girard W. Levy of Battelle Memorial Institute is undertaking a national survey of industrial and governmental organizations employing scientists and engineers. The survey is focusing on the magnitude of continuing education activities, employee motivation for participating in continuing education, and the degree of employee satisfaction with participation. This survey will be an important first step in formulating policy and progress to deal with career development of scientists and engineers.

Little information is available on the effect of calculators on mathematics education in the elementary school. With RISE support, Grayson Wheatley of Purdue University is directing a coordinated effort to assess the effect of hand calculators on the learning of concepts and basic facts, mathematical computation and application, and student attitudes. The project is being carried out at five sites (Indiana, Iowa, Michigan, Missouri, and Ohio) and

involves 50 classes in grades two to six. Similarly, a research project at the University of California, Berkeley, under the direction of W. M. Laetsch, is concerned with determining the value of science instruction on decision-making and how educational programs could be modified to have a greater effect on this everyday process. The project is evaluating scientific reasoning in laboratory and naturalistic settings as well as in informal activities and games employing 7th, 9th, and 11th grade students in three different socioeconomic areas. The project is also determining the impact on everyday decisionmaking.

A project under the direction of John Falk of the Smithsonian Institution is conducting a series of studies intended to increase understanding of student learning and behavior during outdoor field trips and to provide suggestions that will allow for improvement in the efficacy of outdoor-centered science education. The studies are designed to determine how factors such as bus rides and disruption of normal schedules interact with learning and behavior on field trips. The perceptions of educators toward field trip experiences for children, the effect on learning and behavior of the setting of the field trip, and the number of relevant examples to which the child is exposed are also addressed.

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## Science and Society

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

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



**Table 8**  
**Science and Society**  
**Fiscal Year 1977**

(Dollars in Millions)

	Preliminary Proposals		Proposals		Awards	
	Number	Amount	Number	Amount	Number	Amount
Public Understanding of Science .....	300	\$18.00	57	\$ 8.56	29	\$1.97
Ethics and Values in Science and Technology .....	430	38.00	92	9.10	20	1.21
Science for Citizens .....	289	9.83	233	4.15	48	.91
Forums, Conferences, and Workshops .....	289	9.83	62	2.00	19	.54
Public Service Science Residencies and Internships .....	—0—	—0—	171	2.15	29	.37
<b>Total .....</b>	<b>1,019</b>	<b>\$65.83</b>	<b>382</b>	<b>\$21.81</b>	<b>97</b>	<b>\$4.09</b>

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

## Science for Citizens

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

Fiscal year 1977 was the first year for NSF's public service science residency and internship awards, which enable scientists, engineers, and students of science and engineering to undertake up to a year's activities with citizen groups and other appropriate organizations in need of their expertise.

The following are examples of the 29 projects being undertaken by fiscal year 1977 residents and interns:

- In association with the Texas Public Interest Research Group, an intern is examining alternative approaches to controlling flooding and storm-water pollution in two Houston watersheds and is conducting a program of public education on this subject.

- Two residents, serving as science adviser and science writer for the *Smithfield Times*, a weekly Virginia newspaper, are treating a series of technological issues facing the community and assisting in the development of town meetings to discuss these issues.
- A resident is preparing materials on occupational health and developments in the study of industrial disease for dissemination, through training sessions, meetings, and publications, to members of the Oil, Chemical, and Atomic Workers Union.
- A resident is consulting with the Citizen/Government Transportation Planning Center of Windsor, Conn., on the interpretation of technical information on air pollution, the preparation of public information materials, the arrangement of public seminars and workshops, and the direction of staff research and planning.

NSF-supported forums, conferences, and workshops bring citizens and scientists together to educate each

other about science-related policy issues. The following are examples of the 19 such activities that received support in 1977.

- The American Society of Civil Engineers conducted a 2-day conference in Colorado to increase the awareness of home buyers and homeowners, local government agencies, the financial community, the insurance industry, and others, of the potential hazards of swelling and shrinking soils in the area.
- Appalachia-Science in the Public Interest conducted a conference in Kentucky to increase citizen access to scientific and technical expertise on the problems of surface coal mining and blasting and to initiate a continuing dialogue among citizen, industry, and government interests concerning development of a public coal policy that ensures the integrity of the human and natural environment.
- The educational affiliate of the International Ladies' Garment Workers' Union of Puerto Rico (the *Comite de Trabajadores para Ayudar al Consumidor, Inc.*) is sponsoring a major conference, a series of leadership training conferences, and a series of plant- and community-level presentations directed at developing understanding of science-related health policy issues among the memberships of trade unions and organizations of low-income families in the Hispanic community.
- The University of Hawaii is conducting a statewide program of symposia and workshops to raise the level of public understanding of energy and energy-related matters. The

results will be integrated into option plans for energy policy to be considered by the 1978 State legislature.

- The Town of Lexington Forum on Aging Committee is cosponsoring a forum series on research on aging with the American Association of Retired People. Lexington senior citizen organizations, the League of Women Voters, biomedical and social scientists, and the Lexington churches and synagogues will contribute to the forums, which will focus on the propriety of biological experimentation to modify the rate of human aging and the social and medical consequences of the extension of the healthy middle years.

The science for citizens program has also begun to plan the development of public service science centers and institutes, which are intended to provide ongoing support for citizens and scientists who wish to work together to achieve SFC goals.

Two new reports prepared for the SFC program are available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22161: *Technical Information Outreach Programs for Citizens and Citizen Organizations: A Review of Program Models*, PB No. 266576/AS (\$4.50); and *Implications of NSF Assistance to Nonprofit Citizen Organizations*, PB No. 266565/AS (\$10.50).

### Ethics and Values in Science and Technology

The ethics and values in science and technology (EVIST) program is directed toward increasing understanding among the general public and in the scientific and technological communities of the ethical problems and conflicts associated with contemporary scientific and technological

developments; the impact of changing ethical and social standards on the scientific and technological enterprise, including issues raised in establishing research priorities and in regulating the conduct of research; and the processes that generate value conflicts among scientific and social groups and institutions, as well as the processes that may lead to their resolution.

During 1977 the program continued to support analytical and case study research on ethical and value issues associated with specific developments in science and technology; the compilation of archival materials; and workshops and symposia organized by national organizations. Of the 15 EVIST awards made in fiscal year 1977, four workshop projects were supported. These included:

- A workshop on ethics in computer science and technology, organized at the Stanford Research Institute, and its proceedings, prepared for publication by the American Federation of Information Processing Societies.
- Three workshops on ethical problems of psychologists working in the criminal justice system, sponsored by the American Psychological Association, which also prepared a set of draft guidelines for consideration by its membership.
- A workshop on toxic substances and trade secrecy, organized by the Technical Information Project of Washington, D.C., which brought together interested parties in academia, industry, government, and public interest organizations to discuss their differing value perceptions and to lay a foundation for continuing communication.

Also completed during 1977 was a modular text, *Science and Ethics*, intended for use in institutions of higher

education. The text is one of several units of the Science in a Social Context project, which introduces social aspects of science into both introductory and advanced undergraduate science courses.

Five grants were made jointly by the EVIST program and the National Endowment for the Humanities. These included a study of ethical and social problems encountered in research on violent behavior and research on the ethical foundations of benefit-cost analysis techniques and the application of those techniques in evaluating public policies.

Three awards were made for studies related directly to value issues involved in the formulation and implementation of public policies. One study is exploring the ethical and legal issues encountered by Federal science-related regulatory agencies in managing scientific and technological developments associated with uncertain costs, uncertain benefits, and uncertain risks. Another project is preparing an in-depth analysis of the equity issues associated with various technical options for radioactive waste disposal. A third project is studying the processes through which values become involved in the discipline of economics, and how those values affect the development of national economic policy. EVIST also supported research to develop and test a set of procedures, based on social decision theory, for effecting value trade-offs between social groups in various technology-related policy areas.

Two grants were made for projects with explicit international dimensions, one for an international symposium on value issues associated with appropriate technologies in developed and less developed countries, and another for a study of value issues associated with the transfer of rice production research and technology from the United States to the countries of South Asia. A project to compile and make accessible printed and oral

materials on the continuing controversy over recombinant DNA research received continued support.

### Public Understanding of Science

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

By utilizing a wide variety of communication techniques and responding to the needs of many groups, the program has begun to reach a large audience. Examples of the scope of PUOS outreach include the traveling exhibits of the Association of Science-Technology Centers, which are circulated to science centers with an annual attendance of 36 million people; the NOVA public television programs, which are seen by 4-7 million viewers each week; and the mass media intern

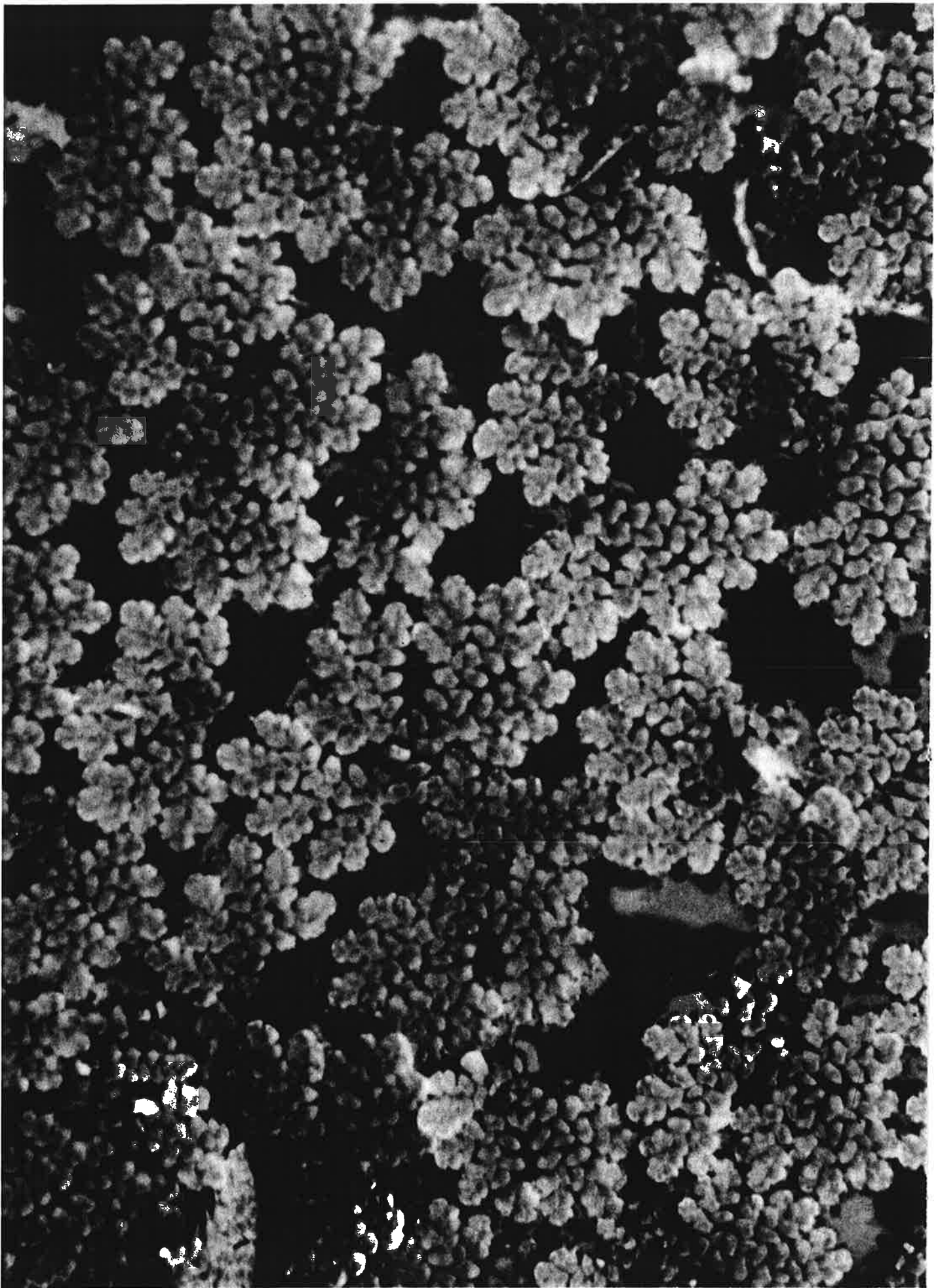
program of the American Association for the Advancement of Science, through which young scientists gain experience writing science articles for newspapers and broadcast stations throughout the country.

In total, 31 projects were supported in fiscal year 1977, including the following innovative communication programs.

- A regional science program consortium, formed under the leadership of KPBS-TV, San Diego, will collaboratively produce programs about science-related policy issues for broadcast on 40 West Coast public TV stations.
- The Children's Television Workshop has begun feasibility and planning studies for a daily science program that will provide an introduction to the methods and activities of science as well as indirect support to classroom work and role models for potential careers in science.
- "Science Scene," a weekly radio series produced by the Science Program Group, will deal with the implications of science and technology. In a similar vein, a new television series produced by "Mr. Wizard" will be shown widely on commercial television stations and will discuss topics ranging from flower genetics to solar heating.
- "Voyages Into Ocean Space," a West Coast lecture series about ocean science and resource development, was attended by a total audience of 54,000 and reached an additional half-million people through radio and television; it resulted in over a hundred newspaper articles in West Coast cities.
- "Glass," a dramatic presentation by the Otrabanda Theater Company of New Orleans, describes the evolution of a major scientific discovery and its subsequent impact on the course of science.



**Impacts of science.** "Glass," a touring play produced by New Orleans' Otrabanda Company, is a vehicle for illustrating the processes of scientific discovery and the consequences for society. Performing at the Exploratorium in San Francisco, "Joe," the Everyman figure, curses whatever scientific forces are responsible for his faulty TV set; later, during a trip through time, he's aghast at what's happening to him when at the mercy of two medieval physicians. (Photos by Susan Schwartzberg)



# Research Applied to National Needs

# 5

The Research Applied to National Needs (RANN) program, formed in 1971 to bring the resources of science and technology to bear on selected important national problems, has as its goals:

- Identify national needs 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.
- Shorten the lead time 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.

To implement these goals, RANN has focused on the following five major areas:

*Resources*—strategies and new technologies to make possible more effective use of renewable and non-

renewable resources. Emphasis in this program is placed on resource systems and on renewable and nonrenewable resources.

*Environment*—mitigation of environmental hazards, whether natural or manmade. The environmental program focuses on regional environmental management, chemical threats to man and the environment, weather modification, earthquake engineering, and social responses to natural hazards.

*Productivity*—policy research and development of new technologies to improve the productivity of public and private sectors of the economy. The productivity program supports projects in such areas as telecommunications, service delivery, productivity measurement, regulation, distribution and equity, advanced industrial processing, excavation technology, and instrumentation and systems analysis.

*Exploratory research and technology assessment*—research and assessment to understand better the long-range impacts of new technology applications and to study emerging national problems that may be avoided or ameliorated by effective application of science and technology. Research supported by this program includes such subjects as appropriate technology, electronic funds transfer, hail suppression, and controlled environment agriculture.

**Table 9**  
**Research Applied to National Needs**  
**Fiscal Years 1975, 1976, Transition Quarter**  
**(July 1-Sept. 30, 1976), and 1977**

(Dollars in Millions)

	Fiscal Year 1975		Fiscal Year 1976		Transition Quarter		Fiscal Year 1977	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Resources .....	298	\$38.84	159	\$15.20	38	\$ 3.26	101	\$ 9.96
Environment .....	170	23.76	196	26.98	58	6.38	204	24.10
Productivity .....	164	16.94	196	24.11	50	6.36	183	22.14
Intergovernmental Science and R&D Incentives .....	51	2.84	67	4.34	18	1.01	101	6.15
Exploratory Research and Technology Assessment .	17	1.21	19	1.40	2	.41	22	1.38 <sup>1</sup>
<b>Total .....</b>	<b>700</b>	<b>\$83.59</b>	<b>637</b>	<b>\$72.03</b>	<b>166</b>	<b>\$17.42</b>	<b>611</b>	<b>\$63.73<sup>1</sup></b>

<sup>1</sup> Includes \$1.38 million for Technology Assessment in fiscal year 1977.

SOURCE: Fiscal Years 1977, 1978, and 1979 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

*Intergovernmental science and public technology*—integration of science and technology into the activities of State and local governments, and test and evaluation of incentives that the Federal Government may use to increase R&D investment in the private sector where new technology is needed in the national interest. Activities supported include various consortia of cities to use technology to solve local government problems, the National Governors Conference Energy Project, and Innovation Centers at several universities.

In order to provide a more sharply focused scientific and engineering contribution to the solution of emerging or existing national problems and to help build a better bridge between basic research and the solution of such

problems, the Foundation announced on September 15, 1977, the reorganization of the Research Applications directorate. This reorganization grew out of a series of alternatives developed after an intensive study by a special Science Applications Task Force established by NSF Director Richard C. Atkinson and headed by John R. Whinnery, department of electrical engineering and computer sciences, University of California, Berkeley. The new organization calls for the establishment of an *Applied Science and Research Applications Directorate* involving a staff office responsible for problem identification and analysis and four line divisions: integrated basic research; applied research; problem-focused research applications; and intergovernmental science and public technology.

augmented by Colorado State University research on the potential for producing high quality beef on seeded range.

Another project, initiated at the University of Maine, working in collaboration with the University of Rhode Island, is concerned with the socioeconomic implications of extended jurisdiction over fisheries and fisheries management in the Northwest Atlantic. The impacts of various policies and regulations on fishery communities are being studied, with the expectation of integrating the results of this project with the economic modeling of fisheries in progress at the University of Delaware.

Work on the assessment of resource-limited inputs to food protein production systems at Cornell University is expected to result in measurement of the principal relationships of energy, land, and labor inputs to protein production in order to determine the potential for energy conservation and the possible impacts of changes such as the increased utilization of grass-fed beef.

Increasing emphasis is being placed on systems analysis to identify system constraints and the adequacy of the available data base for planning new research programs. NSF supported the University of Virginia to prepare a comprehensive users guide to public systems methodology; this is expected to result in much better understanding and more effective use of systems methodologies at the decision and policy levels.

Research on the reduction of porpoise mortality during purse seining operations in fishing for tuna has been conducted by San Diego State University in collaboration with the Hubbs-Sea World Research Institute. The results of this and other research have made evident the need for alternatives to purse seining. A most promising alternative, the use of an artificial aggregation system for tuna to

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## Resources

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### Resource Systems

This program focuses on research to identify and define critical issues associated with the development, use, and management of natural resources. Particular emphasis is given to studies of the interactions among resource systems, which may identify alternatives for the use of renewable rather than nonrenewable resources. Such studies provide a means to integrate the results of exploratory research on renewable and nonrenewable resources in the problem-solution process.

Research on food resource systems concentrates on alternatives that can enable the United States to address world food problems. A research emphasis in this area has been on beef as a major commodity. Ongoing work on the definition of alternative beef production systems has been

The resources program supports research to identify emerging national problems and to develop alternative policies and technical solutions. Research in renewable resources is concerned with developing innovative systems for synthesis of energy-intensive substances using biological methods, developing nonconventional foods, and developing systems that make possible increased use of biomass. The nonrenewable resources program identifies new technologies for expanding the indigenous nonfuel resource base and studies the causes of mineral shortages and the economic and institutional options for reducing their frequency and magnitude. Resource systems examines the interactions between nonrenewable and renewable resources, the social, legal and environmental constraints, and alternatives for coping with resource problems.



eliminate the need for purse seining, is now under consideration for further research and development.

Research on energy systems has been phased down and further support in this area is not planned, other than meeting the commitments made to ongoing projects. Principal activities have been a long-range energy supply model developed at the Virginia Polytechnic Institute and State University, and a simulation of world oil markets at the Massachusetts Institute of Technology.

### Renewable Resources

The renewable resources program concentrates on three areas—innovative biosynthesis techniques, biomass utilization, and nonconventional foods.

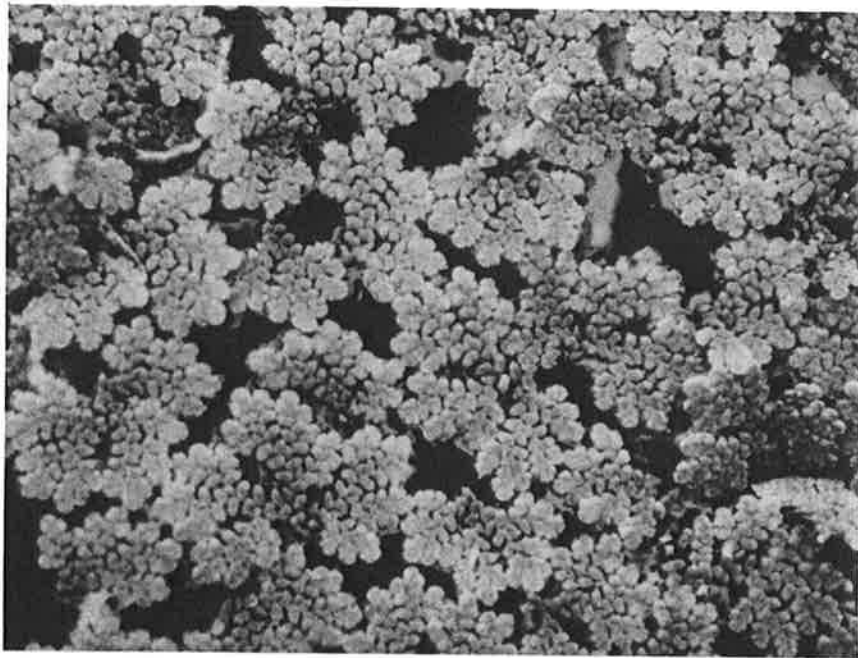
A major area of research on innovative biosynthesis techniques is biological nitrogen fixation. The synthesis of ammonia from molecular nitrogen in the air by various natural biological systems represents the dominant contributor of "fixed" nitrogen on this planet. Every year, approximately 175 million tons of natural nitrogen fertilizer, including 90 million tons on agricultural soils, are fixed by microorganisms; that is, bacteria and blue-green algae. This compares with 40 million tons produced chemically on a worldwide basis through the Haber-Bosch process. The manufacture of chemically produced nitrogen fertilizer, including 9 million tons in the United States, requires fossil fuels, a nonrenewable resource of decreasing abundance and increasing cost. It is therefore important to investigate means to enhance the natural ability of nitrogen-fixing microbes in nature to reduce dependence on commercial fertilizer. This importance has been documented during the past year in publications prepared by the National Academy of Sciences (*World Food and Nutrition Study, The Potential Contributions of Research*) and the Office of Technology Assessment

(*Organizing and Financing Basic Research to Increase Food Production*).

During the past year, research on free-living nitrogen fixation bacteria has continued to provide substantive results. These microbes contain a delicate feedback mechanism that immediately shuts off further nitrogen fixation as soon as sufficient ammonia has been synthesized to meet the growth and metabolic requirements of the organism. A project at the University of Wisconsin, Madison, has focused on producing mutants of the nitrogen-fixing soil organism *Azotobacter vinelandii* that continue to fix ammonia and excrete it into the surrounding environment. Techniques for isolating these ammonia-excreting mutants were devised, and several stable mutant strains were examined with respect to conditions required for optimal excretion. At the University of California, Davis, the ammonia-excreting mutants of *Kleb-*

*siella pneumoniae*, previously shown to produce 400 to 500 percent more ammonia than the parent microbes, were examined for energy utilization. The very high biological energy requirement for these mutant strains of *K. pneumoniae* makes it somewhat improbable that they would be used to produce ammonia directly. However, this high cost can be viewed as beneficial in terms of genetic engineering and possible adverse environmental consequences of "runaway" nitrogen fixation organisms; the exceedingly high biological energy requirement provides a major restraint to any possible contamination of the environment by genetically engineered soil organisms.

With regard to genetic engineering and biological nitrogen fixation, NSF supported Associated Universities, Inc., in putting on two major conferences. The objectives of the first conference, held in March at



**Natural nitrogen fixer.** The water fern *Azolla*, which grows in many parts of the world, acts as a host to a blue-green algae that is a prodigious nitrogen-fixer. The fern grows in rice fields in Southeast Asia and provides needed nitrogen for crop growth. Scientists at the University of California, Davis, are investigating ways to enhance this benefit to temperate rice.

Brookhaven National Laboratory, were to review the current state of genetic engineering as it relates to nitrogen fixation and to assess the opportunities and limitations of this technique for enhancing nitrogen biosynthesis. A major outcome of this conference was the general realization that the current NIH guidelines on recombinant DNA research were not totally appropriate for nitrogen fixation research and plant sciences. The proceedings of this conference, *Genetic Engineering for Nitrogen Fixation*, have been published (A. Hollaender, editor, Plenum Press).

The second conference was held in October at the National Academy of Sciences. It brought this important topic to the attention of a wider group of individuals from the public and private sectors through discussion of the environmental consequences of genetic engineering of *Rhizobium* bacteria which, living symbiotically on the roots of legume plants, fix nitrogen that then nourishes these important crops. The proceedings of this conference will be published by the Government Printing Office.

During the past year, a major research activity involving nitrogen has been started at the University of California, Davis. The overall goal of this multicomponent research project is to use solar energy to enhance the production of ammonia from nitrogen gas or soil nitrate by biological means. Major objectives are to: (1) enhance the nitrogen-fixing capability of natural bacteria by genetically constructing superior mutants; (2) increase the efficiency of symbiotic nitrogen fixation in legumes by identifying naturally occurring genetically constructed variants of the *Rhizobium* bacteria and the host legumes; (3) maximize nitrogen fixation in cereals, especially rice, through the use of the symbiotic water fern *Azolla* and blue-green algae *Anabaena*; and (4) conserve fixed nitrate nitrogen by genetically modifying typical soil microorganisms and by identifying and controlling the

regulatory steps of nitrate assimilation in plants.

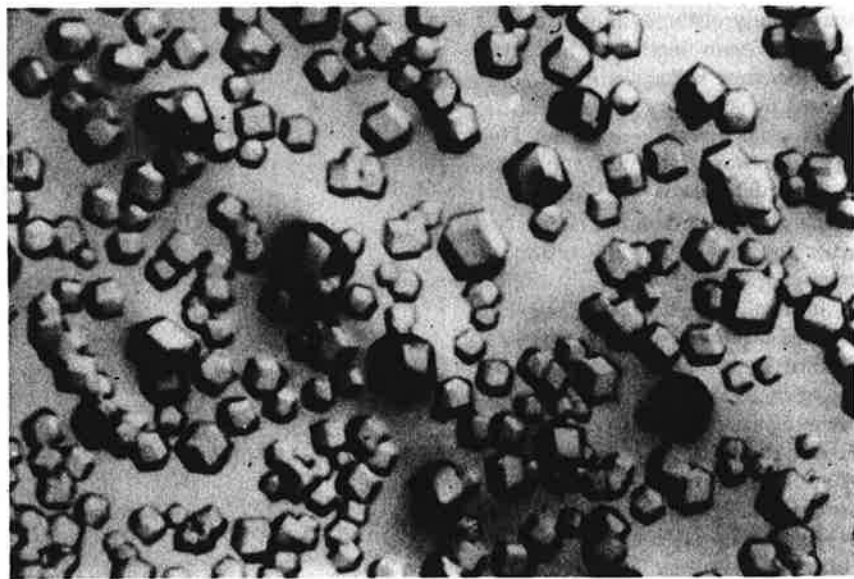
Research on biomass utilization has been extended to include the production of specialized biomass materials. A good example is natural rubber from the guayule plant, a shrub native to semiarid highlands of northern Mexico and western Texas. During World War II, an emergency rubber project was supported by the U.S. Government to develop guayule as a source of natural rubber, but the effort was abandoned after the war when natural rubber from the *Hevea* plantations in Southeast Asia again became plentiful. Recently, in the face of continuing importance of natural rubber as a critical material in the economy of the Nation and the concentration of the supply in a few countries in Southeast Asia, a National Academy of Sciences (National Research Council) panel recommended that guayule be developed as an alternative, domestic source of natural rubber.

NSF-supported research at the California Arboretum Foundation in

Arcadia and at the University of Arizona seeks to reestablish the guayule germ plasm base. The objective is to improve significantly the 1940 strains in order to increase rubber yields. The selection program should tend toward strains of guayule having a high rubber and lower resin content, increased disease resistance, increased vigor, and wider adaptation.

The leaf protein project at the University of Wisconsin has focused on the development of an on-farm system to harvest, process, and use forage, such as alfalfa, in three forms: (1) a coagulated protein concentrate for feeding chickens and swine; (2) a pressed residue to be fed to dairy cows; and (3) a spent juice to be sprayed back on the land as a fertilizer. A linear programming model of the operation has been constructed, and early results suggest that the proposed farm system may be economically advantageous for a typical Wisconsin dairy farm when compared with the traditional system.

Another leaf juice protein investigated during fiscal year 1977 is



**Pure protein.** Biologist Sam Wildman at UCLA has been able to obtain high yields of crystalline protein, which contains neither carbohydrates nor minerals, by a simple procedure from tobacco leaves. Finding better ways to utilize plant leaf proteins may lead to valuable new food resources.

the fraction 1 protein (F-1-P) from tobacco. It accounts for about 50 percent of the soluble protein in plant leaves and is probably the most abundant protein on Earth. Sam G. Wildman at the University of California, Los Angeles, has found that crystalline F-1-P from tobacco leaves can be obtained in high yield. Because F-1-P is a pure protein and contains no minerals or carbohydrates, it is of interest as a diet component in specialized medical cases where control of the type and amount of protein intake is important.

### Nonrenewable Resources

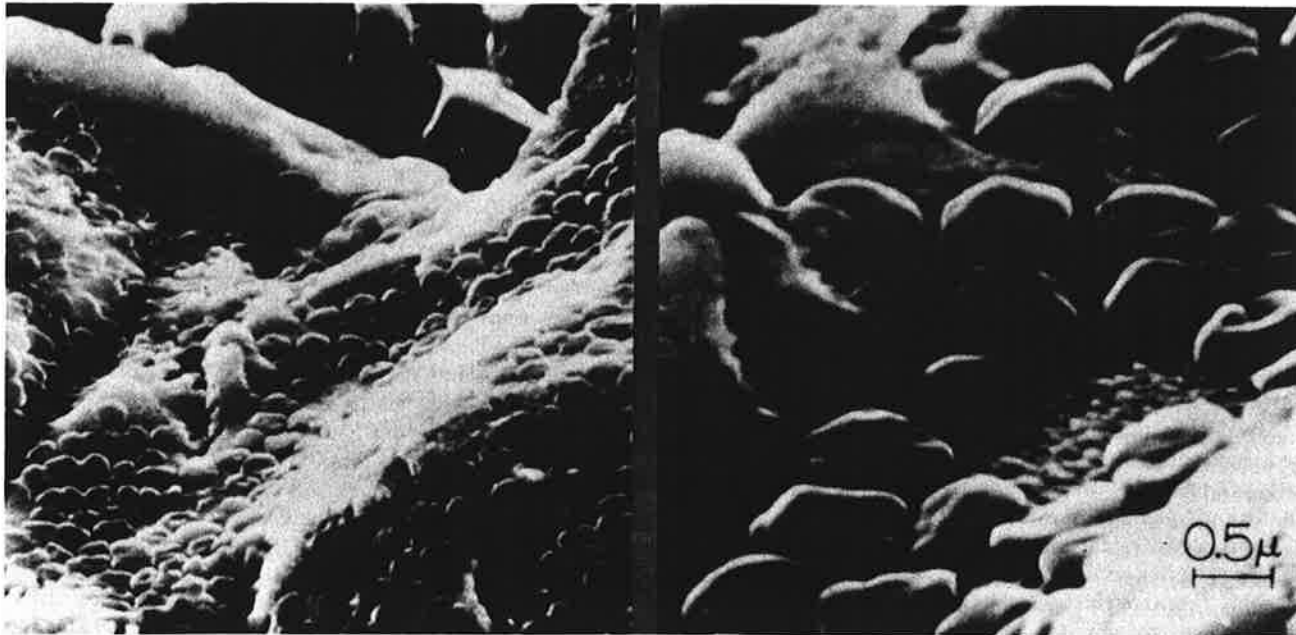
The nonrenewable resources activity addresses selected means by which the United States can seek to extend indigenous mineral supplies. These include substitution; economical processing of high-grade, small, unutilized deposits; finding and extracting minerals from deep and as yet undiscovered ore deposits; recycling;

recovery of mineral values from lower and lower grade ores, mining wastes, and slimes; and better understanding of mineral market behavior.

A project at New Mexico Institute of Mining and Technology studies the more efficient recovery of minerals from low-grade copper ores by chemical leaching of waste by-products of porphyry copper open pit mining. The role of bacteria in the leaching process has been recognized but is not well understood. Laboratory experiments reveal that the solubilization of metal involves a number of interrelated chemical reactions in which bacteria play an important role. These bacteria are more active on certain mineral crystal faces than others, which suggests that different crystallographic orientations of the exposed crystal faces react and thus might play an important role on the rate of reactions involved in leaching. Large-scale bacterial leaching experiments have been carried out in two thermally insulated tanks (10 by 40

feet) with approximately 187 tons of low-grade mine waste rocks. This experimental research, in partial collaboration with the Kennecott Copper Company, has led to improved leaching models. An international symposium on "Metallurgical Applications of Bacterial Leaching and Related Microbiological Phenomena" was recently held at New Mexico Institute to stimulate interaction between microbiologists and metallurgists in the creation of more coherent understanding of the biometallurgical aspects of leaching.

To identify high priority research for developing new exploration and extraction techniques applicable to other mineral deposits not accessible by conventional methods, NSF supported three workshops in fiscal year 1977. "Research Frontiers in Exploration for Nonrenewable Resources," held at the Pennsylvania State University, identified the research needs in economic geology and geochemical exploration. Results of the University



**Copper processing.** Scientists at New Mexico Institute of Mining and Technology are studying the role of bacteria in the chemical leaching of low-grade ores to recover copper. (The bacteria are shown selectively attached to a particular mineral phase on the ore surface.) Such leaching processes may permit efficient recovery of additional resources that now go unused.

of Utah's "Workshop on Mining Geophysics" were reported in *Geophysics*. Findings of the third workshop, conducted by Stanford University on long-range research needs in deep solution mining, will be published in the spring of 1978.

The Artificial Intelligence Center of SRI International is developing a computer-based consultant system to aid in problems of mineral exploration. The principal function of the system is to engage in an interactive consultation with the user to help evaluate a particular prospect. The project is jointly supported by the U.S. Geological Survey and NSF.

The mineral market behavior program supported research focused on mineral supply-demand analysis, resource policy and regulation, and international aspects of mineral trade and worldwide mineral demand. Research on investment behavior in the U.S. minerals industry continued in 1977, and additional studies were completed for the iron ore, aluminum, and copper industries. In iron mining, it was found that the independent iron-mining companies realized higher profit margins and better inventory



management than mining enterprises operated by the steel industry. Another study, aimed at determining world consumption trends to the year 2000 of 12 key minerals, has concluded that the income elasticity of demand for these minerals in rich lands, where most are consumed, has been declining in recent years.

the atmospheric environment. The program is directed toward developing a broader base of scientific knowledge for environmental decisionmaking than that which can be achieved by research in response to current regulatory and mission agency needs.

Epidemiological studies of medical personnel assigned to operating rooms have shown that they are subject to increased spontaneous abortion, birth defects in their children, and cancer compared to medical personnel who do not work in operating rooms. The increased risk of birth defects is also observed in the wives of male operating room personnel. These findings suggest that inhalation anesthetics may be mutagens, teratogens, and/or carcinogens. NSF-sponsored research at the University of Texas Cancer Center has examined three of the most widely used anesthetic gases for mutagenicity, using mammalian cells and new assay techniques developed by the University of Texas team. Chromosome breakage, the usual measure of mutagenic potential, was not increased by the gases. However, use of new cytogenetic techniques showed there was a disruption of the normal cell

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## Environment

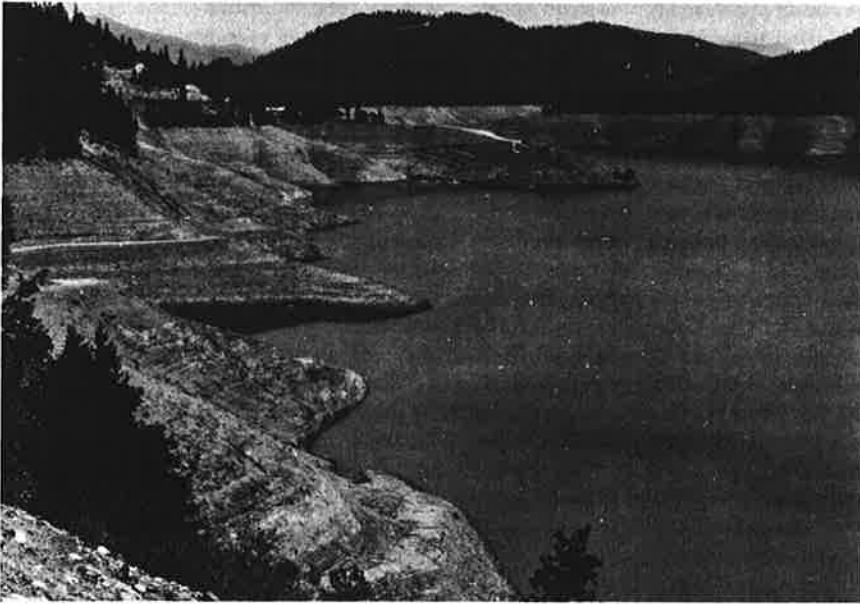
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RANN environmental programs seek to provide an improved scientific basis for the mitigation of man-caused or naturally occurring environmental hazards. Within the context of man-caused hazards, the objective is to identify major environmental hazards, evaluate and quantify the associated risks, and synthesize methods for more effective risk control or management. This requires the identification of those environmental hazards associated with human activity, the improved evaluation of the significance and extent of these risks,

and the identification and assessment of procedures for reducing impacts and enhancing environmental quality.

### Chemical Threats to Man and the Environment

This program focuses on the environmental and human health impacts associated with releases of chemicals and anthropogenic by-products into the environment. Emphasis is placed on organic chemicals of commerce and human alterations of



**California drought.** Researchers in the San Francisco Bay Area are studying supplier and consumer reactions to the 1977 water shortages with the objective of recommending better water management strategies. The impact of that drought is seen in two views of Clair Engle Reservoir, full (2.4 million acre-feet) in 1974 (left page) and down to 460,000 acre-feet in August 1977 (above). (Photos by U.S. Bureau of Reclamation)

division process as seen by interference with segregation of the chromosomes to the daughter cells. The DNA of the cells was not directly affected, and the adverse effects of these chemicals would not be detected if bacterial test systems were used. The conclusion can be drawn that while bacterial cells are useful for showing which chemicals react with DNA, a total assessment of mutagenic hazard to humans requires a more complete look using a system that better represents cell division of humans. Further development of the mammalian techniques is continuing, and a protocol for testing chemicals in mammals is being prepared under continued NSF support.

With the enactment of the Toxic Substances Control Act (PL 94-469) on January 1, 1977, the Federal Government now has the authority to require premarket testing for the determination of the hazardous nature of new chemical substances and mixtures and

the testing of existing materials in current, widespread use. The provisions of the Act established an eight-member Interagency Advisory Committee to the Administrator of the Environmental Protection Agency to set priorities for the testing of chemicals. The first mandated list was required to be transmitted by October 1, 1977. In order to carry out the mandate of the Interagency Committee, NSF made an award to Clement Associates, Inc., Washington, D.C., to provide technical assistance to the Committee. Under the direction of John C. Kolojeski, a team has provided information on the production, release, exposure profiles, and toxic effects of a very large number of manufactured chemical substances and mixtures. In addition, the project staff has provided consultation to the Committee on procedures for establishing priorities among the array of substances and mixtures that will require further toxicological examina-

tion according to the provisions of the Act. This effort extends previous and current research into the first phase of research utilization relating to hazard prioritization of industrially synthesized chemical substances and mixtures.

### Regional Environmental Management

Economic and technological developments outstrip our abilities to deal with environmental problems that accompany them. These problems are immense and are made extremely complex by an interplay of natural, sociological, technological, and economic forces. A regional approach appears to be the most appropriate level at which to confront complex systems; the region may be considered an area that forms an essentially complete and boundable environmental system, within which one may measure and study population changes and energy and material flows. The scope of the regional environmental program consists of research on the environmental impairments (hazards) of selected regions and their component and interrelated factors, including economics, growth, resource availability, and social, institutional, organizational, and physical constraints. The research is directed toward establishing a scientific base for developing new technologies and strategies for the decisionmaking process regarding the management and use of regional environments.

The current urban water shortage in California has already affected the lives of millions of Americans. If the drought continues through 1978 the situation in this State, the most populous of the Nation, may become critical. Agricultural drought has been studied exhaustively in the past; there is, however, a paucity of analytic work on urban drought. Significantly, several critical issues are specific to drought in an urban context. These include the multiplicity and fragmentation of local water agencies in urban



areas, the competition between large numbers of municipal and industrial water users, the greater opportunities for conservation by residential homeowners, and the larger demands for high quality water in densely populated regions.

Researchers at Teknekron, Inc., a consulting firm in Berkeley, Calif., and University of California staff from the Berkeley and Davis campuses are studying the impacts of supplier and consumer response to the droughts in the San Francisco Bay Area. Seven counties of the Bay Area are the subject of this work, and some reactions and perceptions of the users to pricing policies, conservation, regulation, allotments, and rewards have already been determined. This information will be useful in the implementation of better policies to ameliorate or minimize the overall societal costs. Finally, the project will develop a series

of recommendations aimed at physical, legal, institutional, and/or behavioral changes, for the short and long term, that will facilitate the adoption of improved drought and nondrought management strategies. The applicability of these considerations to more general natural resource management policies will be considered.

Research at the Public Service Electric and Gas Company, under the direction of C. R. Guerra and B. L. Godfriaux, with the cooperation of Trenton State College, Rutgers-The State University, Long Island Oyster Farms, and the State of New Jersey Department of Agriculture, is developing a new application for the use of low-grade powerplant waste heat through aquaculture. An outgrowth of this project has been the introduction of the concept of diseasonal aquaculture—the culture of a warm

water species during the warmer months of the year and a cold water species during the cooler months. Recent research has revealed that both rainbow trout and the freshwater Malaysian shrimp *Macrobrachium rosenbergii* can thrive with accelerated growth rates in the heated effluent of a coal-fired generating station. Rainbow trout harvest-time densities in the heated effluent reached commercial production levels. At the present time, through increased water flow and vertical substrates (netting) for the freshwater shrimp, it has been possible to triple the production density of these shrimp in comparison to what has been achieved in pond cultures.

If the thermal discharge waters of about 10 percent of the fossil-fueled steam generating stations were used to produce trout or catfish, it is estimated that waste heat aquaculture has the potential of becoming a one-half-billion-dollar-a-year industry in the United States. An electric generating station, in the 400-megawatt range, could produce between \$2.6 and \$5.2 million in additional yearly net revenue from aquaculture.

### Earthquake Engineering

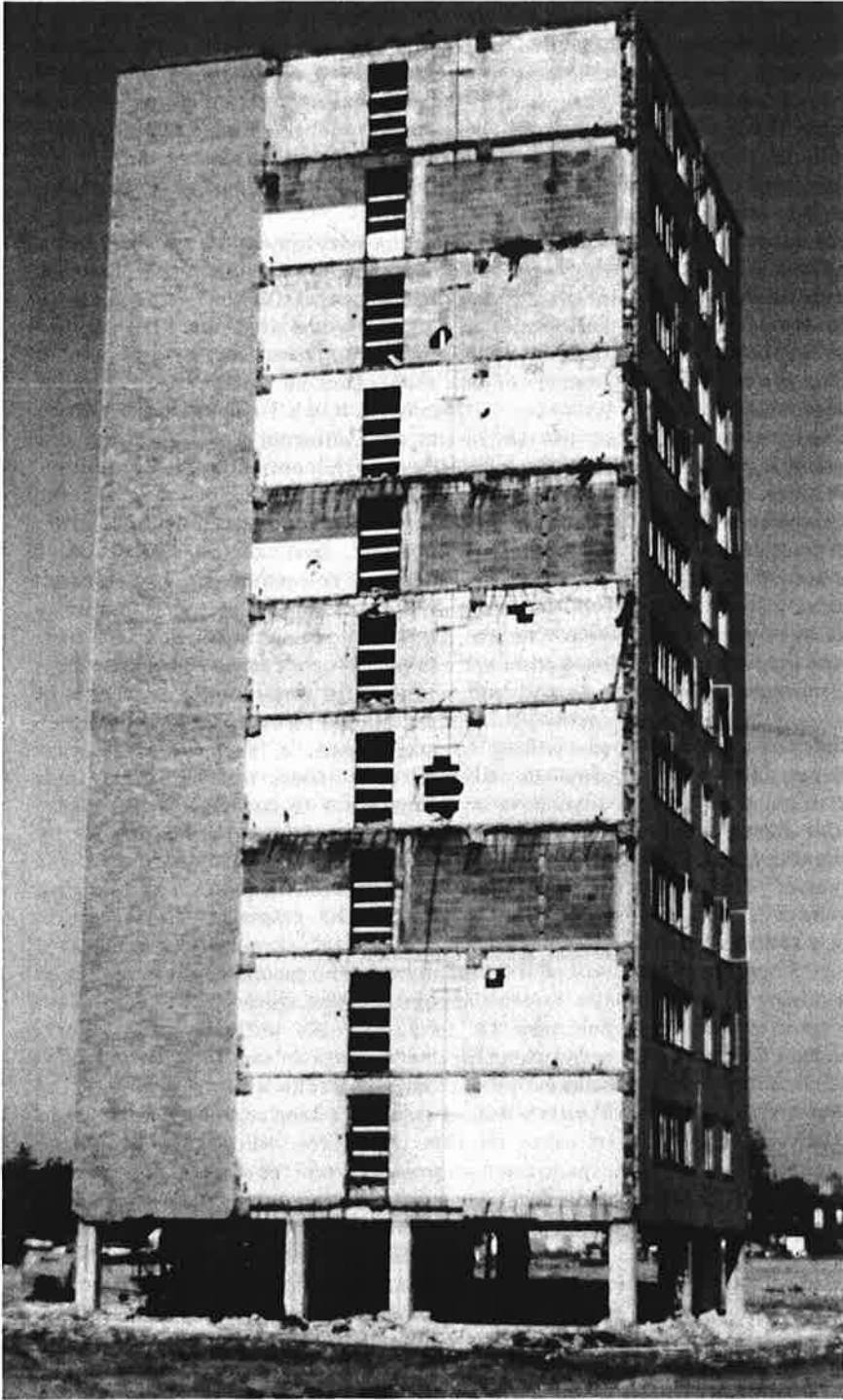
Earthquakes are one of nature's severest geophysical hazards. Portions of 39 States with 70 million residents are in areas subject to major or moderate seismic risk. Although damaging earthquakes are relatively rare at a specific site, they can have a continuing impact on the community through increased investment on capital structures, restricted land use, condemnation of hazardous structures to achieve adequate earthquake performance, and the maintenance of preparedness programs and payment of insurance premiums. The goal of the earthquake hazard mitigation program is to help reduce casualties, damage, and social and economic disruption from earthquakes.

The demolition of the Pruitt-Igoe Public Housing Project in St. Louis,



**Waste heat aquaculture.** In an experiment at a coal-burning electric generating plant in New Jersey, low-grade waste heat in condenser cooling water is recovered to warm an aquaculture pond, permitting the cultivation of shrimp in the warmer months and, shown here, rainbow trout in the cooler months. The research results suggest that the technique is technically feasible and has strong commercial potential.





**Shaking test.** Washington University at St. Louis faculty engineers took advantage of the planned demolition of the Pruitt-Igoe housing structures in St. Louis to conduct simulated earthquake tests of this building. Results will be useful in the design of modern structures and in evaluating the safety of existing ones.

Mo., provided Washington University researchers with a unique opportunity to test one of the 33 units for seismic resistance prior to its planned destruction. The project, which opened in 1956, consisted of 11-story apartment units of reinforced concrete columns and floors constructed at a time when the local building code specifications did not include earthquake safety features. The building test conducted by the Washington University team was carried out by horizontally oscillating a 60,000-pound mass of lead weight, placed on the 11th floor, by a system of hydraulic jacks. Instruments to measure the accelerations and deflections were placed at various locations throughout the building to record these data as the building was being stressed. During the test, which was sufficient to cause the top floor to sway a maximum of 28 inches, translational and torsional vibrations produced rupture of wall and beam-to-column connections in the lower stories. The results of this test indicated that seismic resistance features can be incorporated into the design of these types of structures at a relatively low cost. The data obtained from the test are also being used to verify structural analysis methods and to establish design criteria for the evaluation of the safety of existing buildings as well as for new construction.

Important technical education activities were carried out during 1977. The Earthquake Engineering Research Institute, a national organization of professionals interested in earthquake mitigation, conducted three seminars during September 1977 to disseminate the latest research results to professional engineers engaged in seismic design. In addition, the American Institute of Architects Research Corporation conducted a 1-week summer institute on earthquakes and their relationship to the architectural profession.

Paul Weidlinger Associates, an engineering consultant firm in New

York, has studied the behavior of underground lifeline structures such as pipelines, conduits, and channels in seismic areas. The study has demonstrated that the pipe usually fails due to relative motion rather than rigid body motion in earthquakes. In a number of earthquakes, pipes survived in both hard and soft soil conditions, but they were severely damaged in transition regions. From this research, improved design procedures and specifications are being developed for possible adoption by the utilities.

### Weather Modification

Weather modification research seeks to provide the scientific basis for determining the feasibility of weather hazard mitigation. These mitigation procedures were viewed from two perspectives—those cases where a deliberate attempt is made to alter directly atmospheric events such as the occurrence, duration, and intensity of precipitation; and the inadvertent, unplanned changes in regional weather patterns due to the discharge of materials and heat into the atmosphere and to widespread alterations in surface land form by agriculture, transportation, industry, and urbanization.

Currently, one of the major obstacles to determining the success of field tests of weather modification technology is the lack of conclusive and economical evaluation techniques. Part of the problem results from the inability to forecast accurately the amount of precipitation that would normally occur from any given cloud system. The incremental effect caused by weather modification activities is therefore difficult to determine. This difficulty is greatly accentuated by the large natural variability in precipitation events. These two factors—forecasting uncertainties and the great variability of natural precipitation—have led to the necessity for randomized experimental field programs

to obtain sample sizes sufficient to permit evaluation of the results.

Research efforts currently supported at the University of Virginia include the statistical analysis of the results of the Florida Area Cumulus Experiment (FACE) and the tracing of the silver iodide seeding material used in the experiment to determine where the silver iodide goes and how much of it ends up in the rainwater. Results to date provide strong indications of a significant increase in precipitation during the exploratory phase of FACE as a result of the cloud seeding.

Other research is being conducted to develop a set of predictor variables, covariates, and classification variables to aid in the evaluation of hail suppression programs. Inert tracers have been injected into the base of thunderstorm clouds by University of Nevada scientists to study the dispersion of silver iodide throughout the storm and into the rainwater. Elsewhere, researchers at Panhandle State University in Oklahoma have developed a hailstone generator to assess crop damage with variations in simulated hailfall intensity and size of hailstone. Researchers at Colorado State University have discovered important covariate parameters for winter orographic precipitation in the Colorado mountains. These covariates will improve the ability to discriminate treatment effects in winter orographic modification experiments using a significantly smaller number of sampling stations, or permit the evaluation of effects over a much larger area.

### Societal Response to Natural Hazards

Virtually every community is subject to the potential occurrence of several types of natural hazardous events such as hurricanes, tornadoes, floods, and hail. This program concentrates on those pre-impact and post-impact adjustments that are functionally oriented—preparedness plans, warning plans, warning systems,

relief, rehabilitation, land use, and resource management—and that are common to a number of geophysical hazards. Particular emphasis is placed on social, behavioral, and economic aspects of the actions of individuals, families, institutions, and governmental units.

The scientific community may be on the verge of developing the capability to predict destructive earthquakes. In anticipation of this, there is a need to understand how people will respond to predictions so that effective public policy can be developed. Ralph Turner of the University of California, Los Angeles, is investigating the community response to the Mojave Uplift along the San Andreas Fault and other possible premonitory signs of a destructive earthquake. The research will produce a history of community response to a prediction or near prediction and identify people's reception and understanding of reports of earthquake danger, coping steps they are willing to take, extent of their altruistic concern for others, their disposition to cooperate with hazard reduction programs, the process by which people decide about these matters, and the patterns of changing community response. The attention that Turner has given to this threat is one of the reasons that the mayor of Los Angeles appointed a task force on February 23, 1977, to make recommendations for dealing with an earthquake prediction. Members of Turner's project staff have been asked to serve on this task force, whose organization represents one of the major local governmental responses to the occurrence of the uplift.

The Council of State Governments, an organization formed in the 1930's to assist State government in the resolution of problems that are urgent and generic to State government, is examining State government policy options associated with earthquake prediction technology. The basic objective of this project is to examine public policy, legal, legislative, and adminis-

trative issues related to the evolving technology of earthquake prediction, and to translate the results of this comprehensive examination into implementing State and local government programs, as well as programs for the private sector. Work on the implementing programs must begin now so that there is a reasonable

chance that the results will be in place and operational before the technology for earthquake prediction is developed and employed for a real event. The study is including consideration of programs and policies for the secondary effects of earthquakes—such as fire, flood, tsunami—and mitigation measures for these hazards.

Rockford, Ill., the fire department has made interactive instructions a permanent part of their in-service training program. Local agencies in Spartanburg, N.C., are maintaining parent training and senior citizens programs that were tested under the NSF-supported research program.

Research on the effects of television advertising on children was assessed by a group at Harvard University, the University of Pennsylvania, and Hartford University, advised by representatives of industry and public interest groups. It was determined that available evidence shows that advertising does affect children, particularly very young children. The key contribution of the study is the identification and clarification of areas of public policy where research findings can be used meaningfully, areas where additional research is needed, and areas where social science is not relevant. The study is being used by the Federal Trade Commission in deliberations on children's advertising.

The economic role of "information" industries and occupations in the U.S. economy was defined and measured in a project supported by NSF and conducted at the Department of Commerce Office of Telecommunications. Based on an analysis of national income and product occupation accounts, it was shown that close to half of the U.S. economy in 1967 was closely related to the creation, manipulation, or use of information. The findings add considerable substance to notions of the "postindustrial" society, and the report describes likely impacts of information technologies and applications on a broad range of private and public institutions.

Helmut Schulz of Columbia University has published *Resource Recovery Technology for Urban Decisionmakers*, a handbook to assist local officials in deciding between various advanced technologies for the economic utilization of municipal solid waste. The handbook critically evaluates 12

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## Productivity

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Research on productivity has become increasingly important in light of the recent declines in the rate of U.S. productivity growth. This decline has major implications for the Nation's economy, and finding ways to improve productivity in both the public and private sectors would be of great benefit. Public policies and private practices dealing with productivity issues are often closely interdependent, and much research is required to understand this interrelationship and its effects. Improvements in productivity have become increasingly important as resources become more costly. Research can make significant contributions to the more effective use of limited resources.

The objective of this research is an improved scientific and technical basis for increasing total factor productivity in the public and private sectors. To do this requires research both on technological means and on improved methods of management to increase productivity, as well as on major constraints to productivity improvement. It also requires research to improve the measures of productivity. Finally, because the program is intended to serve as an important basis for improving public policy decisions, it includes research on distribution and equity issues associated with programs to increase productivity.

### Public Sector Productivity

Emphasis in this program is placed on comparative studies of local organizational arrangements for service delivery, on assessing the social and economic effects of telecommunications in providing services, and on the potential of technology for improving local government operations.

Researchers evaluating the organization of urban service delivery have made available "handbooks" for local decisionmakers to use in assessing local service delivery. A group at Indiana University has published *Policing Metropolitan America*, and researchers at the Research Triangle Institute have issued the *Municipal Fire Service Workbook*. Columbia University scientists have also produced a report for local decisionmakers, *Workbook for Assessing Efficiency and Effectiveness in Solid Waste Collection*. All of these reports are available from the Government Printing Office.

Research begun in 1975 on the use of two-way cable television for providing public services has come to fruition in each of the experimental sites. In Reading, Pa., senior citizens have formed a nonprofit corporation to expand the program of citizen-government interaction and social service information provision. In

different technological processes. The strengths and weaknesses of each process are discussed in detail and an estimate provided of the net cost of utilizing each. The American Public Works Association, the National League of Cities, and the Council of State Governments have distributed the handbook to local officials.

The Institute for Law and Social Research has completed a report showing that of the 17,000 trial courts in the United States, only 6,000 have two or more judges, and only 575 have four or more judges. About 200 courts have access to computers, and about 30 have automated scheduling systems. A user guidebook has been prepared to provide court administrators with a means of analyzing the objectives of their particular court and selecting processes to improve current procedures.

Two books have been published reporting NSF-supported research that investigates how persons with legal needs can more productively utilize legal services. Both of these books deal primarily with the various forms of group legal service plans and insurance for legal services. In the first book, *Prepaid Legal Services: Socioeconomic Impacts*, the authors predict the impacts increasing popularity and use of group plans will have on courts and formal conflict of resolution, on the practice of law, on individuals' costs of legal services, and on their legal well-being. Among the conclusions drawn by the researchers are that as legal representation increases, more disputes having a legal nature will be settled in negotiation with outcomes close to what a court would rule and that litigation will not necessarily increase.

In the second book, *Legal Service Plans*, the various types of plans currently available and likely to be available are reviewed and explained, including the forms and effects of regulation of these activities. Both books are commercially available and add a substantial amount of new information to a rapidly developing area of legal service.

St. Louis County has published a three-part report entitled *School Facility Planning System*. It is based on an evaluation of existing and proposed new methods for forecasting the need for education facilities. A guidebook intended to assist local school districts in assessing their current projection techniques is being disseminated on an experimental basis to 100 schools.

### Public Policy

The basic aim of this program is to provide valid and reliable analyses required for the improved formulation, implementation, and evaluation of public policies and programs that impact on productivity. Particular attention is paid to productivity issues that are or will become important public policy considerations. The four areas of emphasis are: (1) better ways of measuring and improving public and private sector productivity; (2) analyzing the consequences of government regulatory programs; (3) identifying and evaluating the fiscal problems of local government as they relate to productivity and the equitable delivery of services; and (4) assessing the effects of government policies generally on the equitable distribution of productivity gains and losses.

Researchers at Westinghouse Electric Corporation, Carnegie-Mellon University, and the University of Pittsburgh have developed and tested methods and a measuring system for calculating productivity indexes for computer and information services.

A team from Wayne State University and the city of Detroit has developed a productivity measurement system for purchasing departments. The system is based on measures observed in a series of case studies of city, county, and State government purchasing departments.

The University of Oregon had earlier evaluated the efficiency of bidding rules used in the competitive sale of municipal bonds. The research showed that between 25 and 50

percent of all issuers in 1972 and 1973 paid higher than necessary interest. This cost taxpayers between \$20 and \$40 million annually in the present value of higher interest payments over the life of the bonds sold each year. In 1976, resultant cost savings to municipalities and their taxpayers were estimated to total more than \$5 million in present value over the life of bonds sold. In the first half of 1977, use of recommended procedures was up to 35 percent of all municipal bonds sold competitively, up from 22 percent in 1976.

In California, a study by the Rand Corporation provided analyses to the Los Angeles Department of Water and Power used in establishing the utility's experimental, time-of-day, residential electricity rates. Other NSF-supported studies, done by Ernst & Ernst and by the Planning and Conservation Foundation, enabled the California Energy Resources Conservation and Development Commission to examine the impact of alternative electric rate structures on energy conservation.

Projects at the University of Chicago and Duke University have identified some of the economic and demographic issues in maintaining the support level of the aged. The trend toward early retirement that has been in progress since World War II places great stresses on the ability of the working population to support a dependent elderly population. A major conclusion of this research is that the worklife may need to be extended.

Results from a nationwide study of social and occupational mobility in the United States over the past decade show that there has been very little change in rates of mobility over the previous decade. The research, conducted at the University of Wisconsin, also shows that the relative positions of Whites and Blacks have remained about the same even though the Black population had achieved higher levels of occupational status in 1973 compared with 1962.

The use of an improved method of

calculating the costs and benefits of product safety standards developed by the department of consumer economics, University of Maryland, indicated that the flame-retardant standards for children's sleepwear were cost effective but that a standard covering all children's clothing would not be.

A recent report on the housing needs of the elderly from the University of Southern California's Andrus Gerontology Center indicated that current housing policy that favors new housing and age-segregated housing will do little to meet the housing needs of the elderly, who would prefer age-integrated housing and more rehabilitation of extant housing.

A study of consumers' use of package information carried out by the department of psychological sciences, Purdue University, shows that consumers use very little of the information available to them. Public policy to provide more information to consumers needs to select carefully any additional information and provide consumer education campaigns to help people use that information.

### Private Sector Productivity

In achieving its objectives, this program draws upon the large reservoir of technology and applied research capability in U.S. universities and laboratories. This program encourages collaborative programs between industries and universities to complement ongoing industrial productivity efforts and to initiate research in industries, small businesses, and fragmented industries now severely limited in their support of research.

Research at Cornell University introduced computer-aided design and manufacturing concepts to mold design and manufacturing using basic knowledge of fluid flow, heat transfer, rheology, and computer science and technology. A basic computer-aided design program has been developed for the design of simple molds with flat

disk or plate cavities. The results of the research are being made available in the form of a handbook of design charts, which will enable industrial designers to predict pressure drop and clamping force required for the successful molding of large plastic parts, thereby significantly reducing expensive present-day trial-and-error approaches to mold design.

The Charles S. Draper Laboratories has conducted a systematic examination of the research problems associated with the mating of parts, the key aspect of future automatic assembler systems. A new device has been invented for accomplishing this aspect of assembly. These "smart wrists" have widespread application in assembly using present-day industrial robots and transfer machines and give promise of leading to a completely new class of industrial assembly tools.

At the University of Maryland, research on controlled blasting in an urban environment has developed

procedures to reduce the required amount of explosives for specific tasks, as well as reducing noise, vibrations, and flying debris. The ability to control the size of the rock fragments will be a valuable asset to the construction industry. In other research, the feasibility of using radar to determine geologic discontinuities in advance of underground excavation has been established at actual construction sites. Such determinations should reduce the uncertainties in underground construction, resulting in lower costs and increased safety.

A low-cost positron camera became part of a National Institutes of Health-sponsored research program to find improved treatment methods for brain cancer. Research groups in Washington State, Massachusetts, Switzerland, Canada, and Israel are planning similar devices modeled on the University of California San Francisco Medical School design for use in clinical diagnosis.

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## Intergovernmental Science and Public Technology

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### Intergovernmental Programs

Intergovernmental programs facilitate the integration of scientific and technological resources into the policy formulation, management support, and program operation activities of State and local governments. During fiscal year 1977 NSF established the State science, engineering, and technology program, which was authorized by the Congress in the amount of \$3 million. This program provides for grants of up to \$25,000 to State government executive and legislative branches to conduct assessments of the potentials for better mobilizing the scientific and technological resources available to State governments and for developing

plans for using these resources to strengthen State policymaking processes.

In fiscal year 1977, State executive branch awards were made to Alabama, Arizona, California, Colorado, Hawaii, Idaho, Illinois, Iowa, Kansas, Michigan, New Hampshire, New Mexico, North Carolina, Oklahoma, Pennsylvania, South Carolina, and Virginia. State legislative branch awards were made to California, Maryland, Michigan, Montana, Oklahoma, Oregon, Pennsylvania, Rhode Island, and Virginia. Joint awards (combined legislative-executive projects) were made to Connecticut, Louisiana, Texas, and Utah.

In the executive branch program, steps were taken to strengthen ongo-

ing policy management mechanisms in Michigan, Mississippi, Louisiana, and Hawaii to address issues with scientific and technical components of critical concern to the State.

Achievements resulting from executive branch project activities include an analysis of the over 100 multistate, regional organizations in the Western States by the Federation of Rocky Mountain States. This analysis has resulted in the formation of an 11-State organization, the Western Governor's Policy Office. In another project, the Council of State Governments, under its State government innovation transfer program, has identified and validated 14 State-level, first-generation, in-place, wholly State-funded innovations dealing with such areas as health cost containment, State energy management, and financial management.

In the legislative branch program, new or continued support for science and technology activities was provided to such States as Georgia, Massachusetts, and North Carolina, and a major new endeavor was undertaken with an award to the National Conference of State Legislatures to establish and operate a comprehensive information exchange program within the State legislative community. Previously funded projects continued to support activities in the legislatures of Pennsylvania, Minnesota, Wisconsin, and New York. Under another award, the Southern Growth Policies Board, through its legislative caucus, will develop a network of university researchers and a core staff to examine, on behalf of the region's State legislatures, the impact of, and problems inherent in, a period of rapid growth as is being experienced in the South.

In Pennsylvania, the Legislative Office of Research Liaison (LORL) officially began its operation on February 1, 1977, serving as a link between the Pennsylvania General Assembly and research faculty at six State-related universities. In the first 8

months of LORL operation, 67 inquiries had been processed with technical assistance provided from over 300 different responders.

The local government branch program has continued and expanded its support of State, regional, and national innovation networks. During fiscal year 1977, the first annual national conference of innovation groups was held in Burlingame, Calif. The State and regional innovation network system has expanded geographically so that there is one such group in nine of the ten Federal regions—evidence of the growing interest in the issue of science and technology in local government.

During fiscal year 1977, the Center for Local Government Technology at Oklahoma State University combined mass production of prefabricated bridge structures with standardized engineering designs to cut in half the costs of superstructure for small bridges. The State legislature has appropriated funds for fiscal year 1978 to build approximately 15 test bridges. If successful, this experiment could result in enormous savings for State and local governments throughout the Nation. A report prepared by the California Innovation Group detailed annual cost savings or cost avoidance in excess of \$3 million from the implementation of technology-related innovations among members of the group. The Urban Consortium, representing the 28 American cities with populations of over 500,000 and six large urban counties, continued an active year of building a comprehensive R&D agenda for local government.

The science and technology resources program focuses on the scientific and technical resources available to serve State and local governments. The purpose is to help these resources (e.g., Federal laboratories, universities, industry) more effectively meet the scientific and technical needs of State and local governments. The main thrust of the program during fiscal

year 1977 was the Federal Laboratory Consortium and related activities. The consortium now includes over 150 laboratories as members. One project activity in this area resulted in lightweight body armor being transferred to the law enforcement community of the country and to the private sector. So far, an estimated 150,000 police officers are now protected from at least 90 percent of the handgun threats on the street. Within the past year, this technology has prevented the loss of life or serious injury to at least 200 officers.

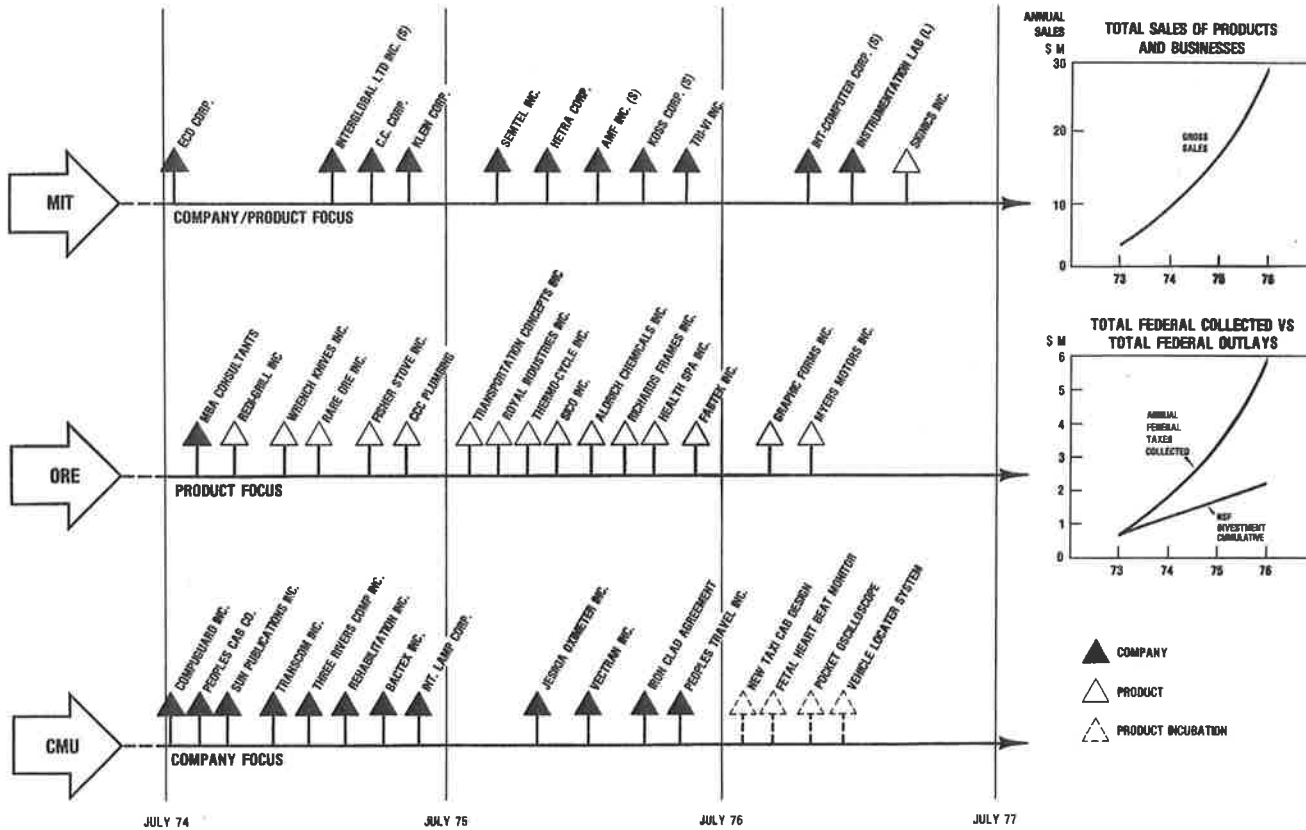
### Industrial Program

The industrial program stimulates increased non-Federal investment in research and development and accelerates 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 overcome the barriers that might impede it.

The concept of innovation centers is being tested in a series of 5-year experiments nearing completion at the Massachusetts Institute of Technology, Carnegie-Mellon University, and the University of Oregon. The primary purpose of these experiments is to test the concept of using university-based research facilities and expertise to support the development of new products and processes, to facilitate the initiation of new technology firms, and to provide entrepreneurial education. This set of experiments has already achieved considerable success, not only in validating the concept of innovation centers but also in the initiation of a significant number of new products and technological firms. The tax revenues generated by these new businesses and products have more than exceeded the cost of the experiments.

Under a series of cooperative research center experiments, university research capabilities have been





**Innovation centers.** Three universities are experimenting with the concept of providing technological assistance to potential entrepreneurs and small businesses trying to develop new products or services. Results, as shown by sales and by tax revenue to the Federal Government, are noteworthy.

used to address industry-identified research problems in fragmented industries, such as the polymer and furniture industries. As these experiments near completion, the Polymer Research Institute at MIT is rapidly approaching financial independence, with industrial contributions sufficient to replace NSF support. The Furniture Institute at North Carolina State has also received significant industry participation and support. Under these experiments several processes and product innovations have been developed and licensed to industry.

A Westinghouse-Stanford Research Institute-Draper Laboratories project has shown that the potential

exists for a four-to-one productivity improvement in batch assembly through successful implementation of adaptable programmable automatic assembly. This project was cited by the Comptroller General of the United States as a textbook example of the way in which the Federal Government and private industry can cooperate with each other and with the university community.

A research project on high-intensity magnetic separation of industrial minerals and ores shows that this new technology should allow the recovery of minerals from ores not now deemed economic. The data, being published in handbook format, have attracted industrial attention, and the concept is

being pilot-tested by industry.

Following a program solicitation for "Small Business Innovation Applied to National Needs," NSF received 329 proposals from small business; the Foundation made 42 awards of up to \$25,000 each for the first phase of a two-phase program. Continuation into phase two will be contingent upon phase one performance, a phase two proposal, program priorities, and the availability of funds. The small business activity not only will support innovative research in important problem areas, but also will stimulate follow-on private venture capital to continue development of the innovation process if the research meets certain objectives.

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## Exploratory Research and Technology Assessment

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The exploratory research and technology assessment program supports research on new opportunities for the application of appropriate science and technology to solve important national problems and to provide information on the social, environmental, and economic impacts of the introduction of major new technologies. Support is also provided to improve the methods used to assess the impacts of technology and to enhance the use of technology assessments by a broad range of decisionmakers.

An assessment of the incipient hail suppression technology was conducted by the Illinois State Water Survey, the University of Illinois, and other research groups. The research team evaluated the hail problem in the United States and then described the key scientific, technological, and societal factors related to the past and present use of hail suppression. This evaluation provided the basis for extrapolating models of what hail suppression's future capability might be; these models formed the basis for calculating the probable future adoption levels of the technology and the resulting social, economic, and legal impacts. These impacts served as a basis for identifying public policy issues, drawing conclusions, and making recommendations, both for public policy and future research. A major policy conclusion is that only through a regional approach could effective hail suppression realize potential benefits.

Systems Control, Inc., of Palo Alto, Calif., completed a preliminary technology assessment of fluorocarbon emission. This study investigated

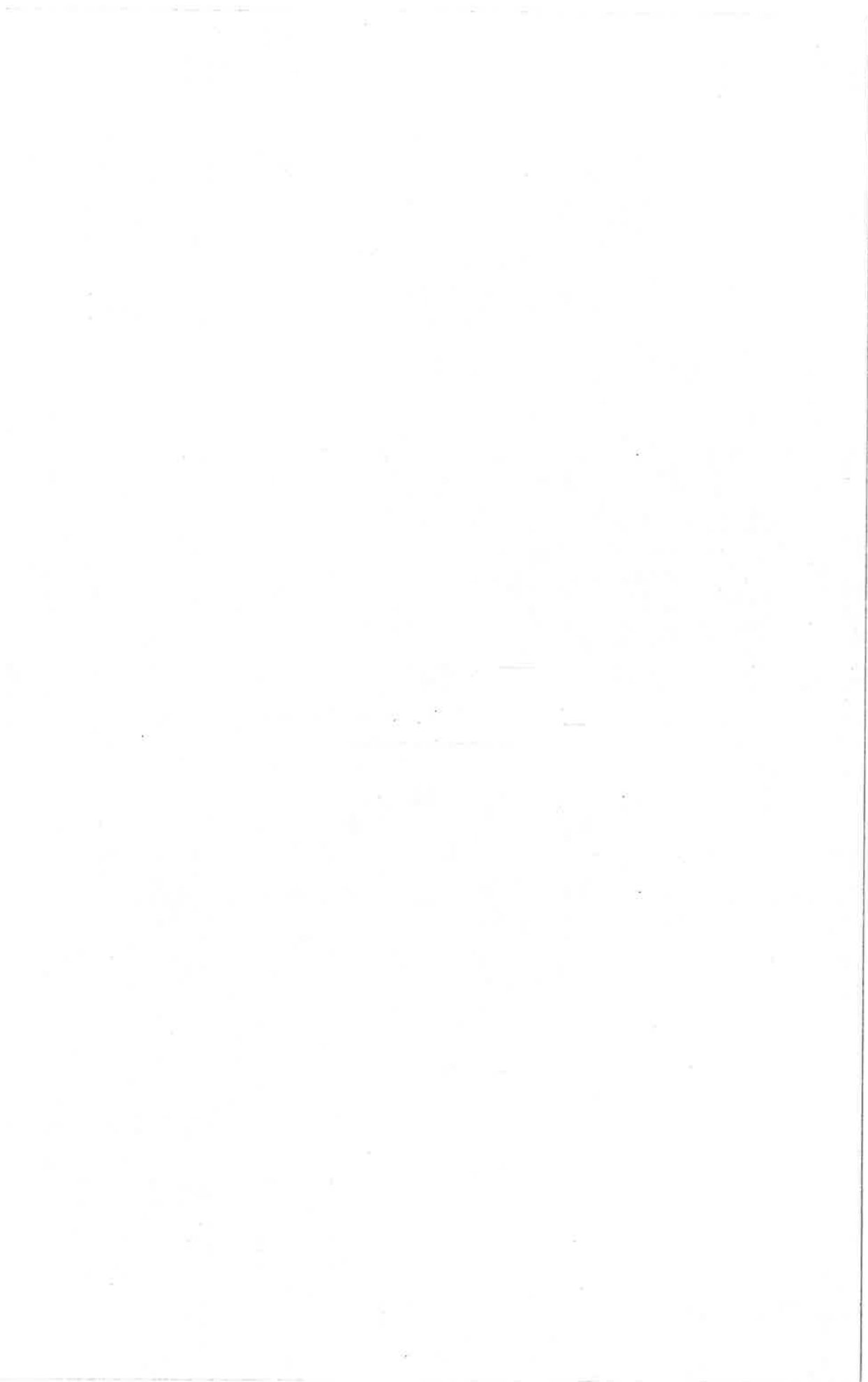
certain physical and economic aspects of the public policy question of whether or not the continued emission of certain types of fluorocarbons into the atmosphere should be controlled. The decision to regulate or not to regulate fluorocarbon production and its uses must of necessity be based upon analyses which involve much uncertainty about atmospheric and biological processes. To help study this complex problem, a probabilistic computer analysis was used to analyze partially the consequences of alternative decision policies. The assessment indicated that eventual regulation of chlorofluoromethane production may be necessary in light of its potential threat to the ozone layer. However, the study showed by contingency analyses that immediate regulation is not mandatory.

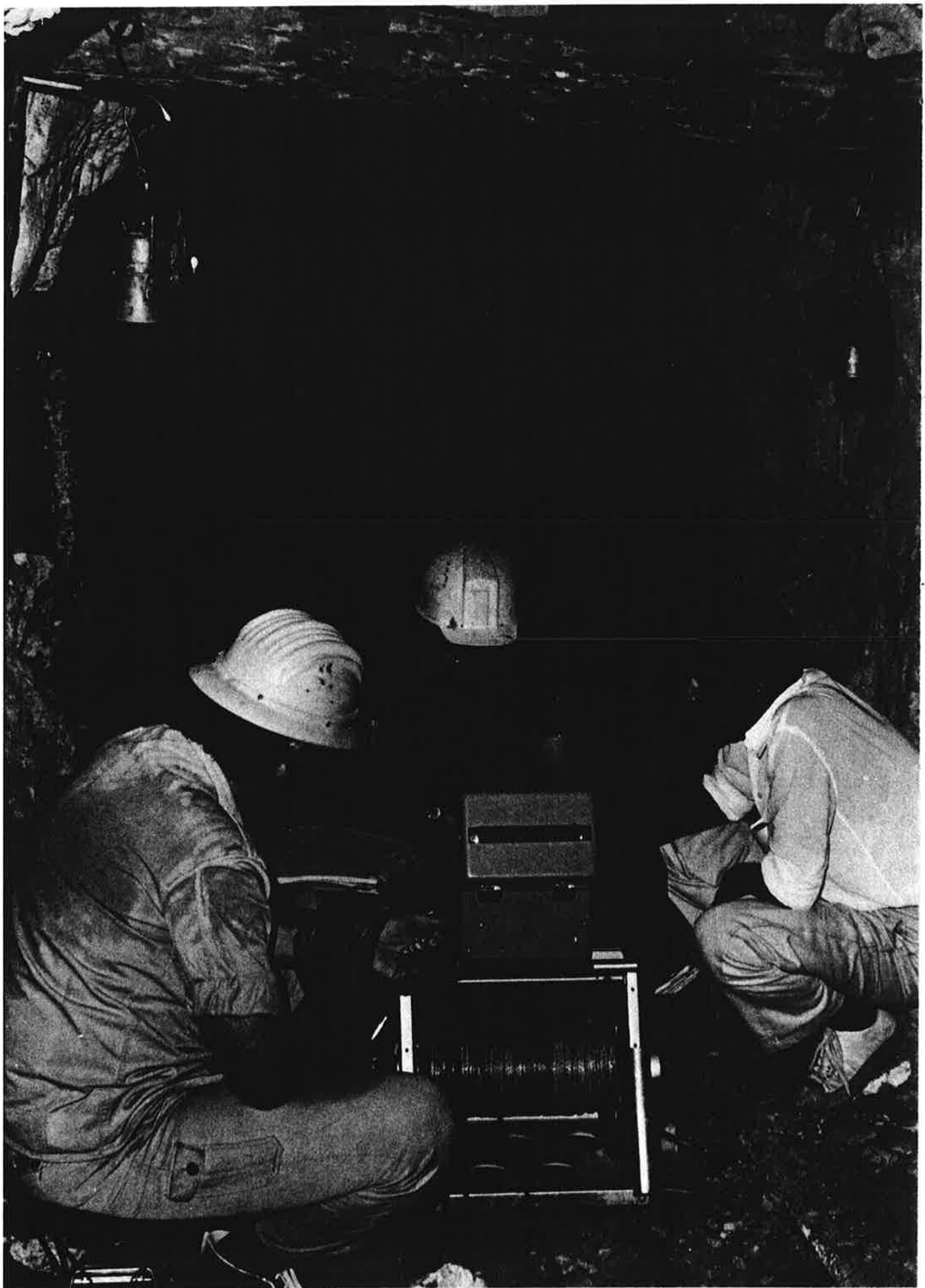
An exploratory study of "appropriate technology" in the United States was completed by Integrative Design Associates, Inc., of Washington, D.C. Appropriate technology is a term that has been applied to technology that incorporates a concern for social impacts, human scale, and for maintenance of the ecological balance by increasing the use of renewable resources, extending recycling and diminishing waste, and fostering the resource independence of local areas. As part of this study, some 300 individuals and groups actively concerned with issues related to the environment, local participation in planning and technology development, and income stabilization/unemployment problems responded to a questionnaire. This covered the scope

of their activities, the legal and technical problems they are facing in moving from idea to application, and their recommendations for Federal activity in support of appropriate technology. *Appropriate Technology—A Directory of Activities and Projects*, a compilation of the descriptions of activities of the survey respondents, is available from the U.S. Government Printing Office.

An assessment of earthquake prediction by SRI International of California studied a wide range of impacts, both benefits and costs, anticipated from the development and use of earthquake-prediction technology. These include the reduction in deaths and injuries from an earthquake, the costs of personnel and supplies for an evacuation, and the loss of economic activity and property values. A major recommendation from this assessment is that in each region in which earthquake-prediction instruments are installed, an earthquake-prediction impact statement should be prepared. This would involve a process of planning for the contingencies that are most likely to result from earthquake predictions in a region and would entail a number of steps leading to the development of a set of response tactics for all possible types of predictions that can be made in a region.

Results of a project to assess the state of the art and needs for additional research in the field of forecasting have recently been published by the Government Printing Office. *The Study of the Future: An Agenda for Research* is being distributed to the community of individuals and organizations that would find it useful, including the Futures Research Group in the Congressional Research Service and the Congressional Clearinghouse on the Future.





# Scientific, Technological, and International Affairs



The Foundation's activities in Scientific, Technological, and International Affairs focus on national and international science and technology issues and on improved communication among scientists and policymakers in the United States and abroad. These activities are centered in three main areas. They are (1) science assessment, policy, and planning; (2) science information; and (3) international cooperative science. Together, these program efforts collect and interpret data, analyze and assess issues, fund research on policy and information science, and administer international activities.

The science assessment, policy, and planning activity includes three programs: policy research and analysis, science resources studies, and NSF planning and evaluation. The policy research and analysis program supports extramural studies and performs intramural analysis of relevant science and technology issues. Work under this program aims at improving public decisionmaking by developing a broad knowledge base for the policymaking process. During this past year, a project was supported to assess the impact of mechanisms used in helping workers adjust to technological changes. Another project, "Towards a Theory of Innovation," documents sources of agreement and disagreement found by empirical studies of innovation in organizations.

The science resources studies program collects and maintains the

national data base on scientific and technical resources, with special emphasis on science and technology manpower and R&D funding. NSF annually publishes more than 20 reports providing comprehensive national overviews, detailed statistical information, analyses of the supply and utilization of science and technology resources, and quantitative indicators of the general health of science and technology. The program provides the staff support to the biennial *Science Indicators* report of the National Science Board. Through the science resources studies program, NSF also supports special studies conducted by the Higher Education Panel of the American Council on

Education. The Panel's 760 members represent 2-year, 4-year, and doctorate-granting institutions, and medical schools. *Educational Attainment of New College Faculty* is one of the surveys carried out by the Panel, which receives support from NSF, the National Institutes of Health, and the U.S. Office of Education.

NSF's planning and evaluation program contributes to the planning, evaluation, and analysis of the Foundation's programs and mission activities. This responds to the Foundation's need to continually improve the effectiveness of its programs.

Science information activities foster the exchange of scientific and technical

**Table 10**  
**Scientific, Technological, and International Affairs**  
**Fiscal Years 1975, 1976, Transition Quarter**  
**(July 1-Sept. 30, 1976), and 1977**

(Dollars in Millions)

	Fiscal Year 1975		Fiscal Year 1976		Transition Quarter		Fiscal Year 1977	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
International Cooperative								
Scientific Activities .....	719	\$ 7.93	690	\$ 7.53	224	\$3.04	712	\$ 8.49
Science Information								
Activities .....	75	5.38	102	5.89	33	.76	84	4.54
Science Assessment, Policy, and Planning .....	172	11.57	218	8.99	71	2.35	178	6.25 <sup>1</sup>
<b>Total</b> .....	<b>966</b>	<b>\$24.88</b>	<b>1,010</b>	<b>\$22.41</b>	<b>328</b>	<b>\$6.15</b>	<b>974</b>	<b>\$19.28<sup>1</sup></b>

<sup>1</sup> Excludes \$1.38 million for Technology Assessment in fiscal year 1977.

SOURCE: Fiscal Years 1977, 1978, and 1979 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

information and improve the communication and effective use of this information. Research leading to improved design, operation, and management of information transfer systems benefits the entire R&D system and facilitates application of R&D results. The results of an NSF-funded study on the future of the scientific journal indicate a move away from the traditional paper-based system towards electronic, computer-based production and distribution of scientific literature.

The Foundation's international programs support participation of U.S. scientists in international cooperative science and technology activities. NSF currently participates in 15 formal bilateral agreements, 9 interacademy

exchanges, 10 joint commissions for economic or scientific/technical cooperation, and special foreign currency programs in 6 countries. These cooperative activities permit U.S. scientists access to unique facilities abroad, help them establish closer ties with foreign colleagues, and aid U.S. foreign policy objectives. The international travel support program enabled 400 U.S. scientists to attend important international scientific meetings and workshops abroad in fiscal year 1977. An example of a cooperative research project is the collaborative work of experts from the United States and France in solid state chemistry aimed at finding new or improved materials for the construction of photoelectrolytic cells.

- *Regulation and Technology Choice in Telecommunications*, a report by Systems Applications, Inc., examining how incentive mechanisms, economic performance, and innovation relate to each other in the telecommunications industry.

### **Analysis of Emerging Science and Technology**

This working group conducted research and analysis to improve the knowledge base for Federal decision-making regarding the effects of science and technology on human and physical environments. Projects included:

- A study by Systems Control, Inc., analyzing the impacts of a proposed national program to eradicate the cotton boll weevil. It was found that the most significant changes in cotton production, consumption, and prices would result from rising energy costs in the entire agricultural system, not from eradication of the boll weevil.
- Substantial progress on the second of two major interagency case studies on wastewater and sludge management planning. These OMB-commissioned studies, the first in Sacramento and the second in Boston, evaluated municipal wastewater management planning in terms of: (1) adequacy of the science and technology information base for decision-making; (2) scientific and technological, economic, and institutional barriers to choosing environmentally sound and cost-effective solutions to water pollution control problems; (3) effects of water cleanup on attainment of other environmental goals; and (4) capacity of communities, States, and the Federal Government to carry out the legislative goals.

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## **Science Assessment, Policy, and Planning**

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### **Policy Research and Analysis**

NSF's programs of policy research and analysis (PRA) are the focal point within the Foundation for study of existing and emerging national science and technology policy issues. This research appraises the impact of research and development on industrial development and the general welfare; assesses Federal and national R&D efforts; examines innovation processes in the private and public sectors; and improves understanding of the relationship between science and technology and national social and economic objectives. In addition, PRA provides information and analysis on science and technology policy issues to the Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB), and other Federal agencies.

Responsibility for research and analysis in fiscal year 1977 was assigned to the NSF working groups described below.

### **The Effects of Public Policy on Science and Technology**

This working group studied public policies that directly or indirectly influence technological innovation in an attempt to understand both what government should use to stimulate technological innovation in the private sector and the effects on technological innovation of policies directed to other public concerns. Projects supported during fiscal year 1977 included:

- A staff report prepared for OSTP, OMB, and the National Science Board describing recent trends and projections regarding the funding and performance of basic research by industry. The study examined the rationale for Federal stimulation of industrial basic research and discussed the advantages and disadvantages of tax incentives and direct grants and contracts.



## The Analysis of International Science and Technology Policy

This working group was concerned with the identification, definition, prediction, and resolution of international science and technology-related issues of concern to Federal policymakers. Projects and activities supported included:

- *A Description and Comparison of the Planning and Management of R&D in the U.S. and the U.S.S.R.*, a report comparing American and Soviet policy and practice in research and development.
- Assistance to the U.S. Department of State in U.S. preparations for the 1979 United Nations Conference on Science and Technology for Development.
- Representation by an NSF staff member on the U.S. delegation to the Third United Nations Conference on the Law of the Sea.
- A project by the Fund for Multinational Management Education examining why multinational corporations decide to locate overseas R&D facilities.

## The Processes of Innovation and Their Management

This working group was concerned with the processes leading up to technological innovation. It focused on the mechanisms that influence innovation in the public and private sectors of the economy and the leverage points for beneficial public action. Projects included:

- *Adoption and Utilization of Urban Technology: A Decisionmaking Study* by Syracuse University Research Corporation describing local government decisions regarding innovative technology.

- *An Investigation of the Adoption of Technological Innovation by Law Enforcement Agencies*, a study performed by the University of Arizona assessing the usefulness of a formal model of innovation adoption in local government. It focused on the utilization of federally sponsored technology by State and local law enforcement agencies.
- Adoption of Innovative Production Equipment by the Domestic Shoe Industry, a briefing on technological change in the domestic footwear industry, for members of the Administration's task force on the shoe-import problem. This briefing was based upon research carried out at the University of Maine.
- The Agricultural Extension Service as a Model Technology Transfer System, the topic of a briefing for OMB and OSTP. It concerned the use of the Agricultural Extension Service as a general model for research utilization and technology transfer in nonagricultural settings. The briefing was based on a joint project involving NSF staff and faculty from Stanford and the University of Michigan.

## Policy Aspects of Energy, Resources, and Environment

This group provided an independent analysis for national energy policy. It supported studies that evaluated energy development strategies, that examined the fundamental scientific or technological constraints influencing energy policy choices, or that evaluated the role of economic, institutional, and regulatory factors in technological choices. Projects included:

- Public Policy Issues in Nuclear Waste Management, a con-

ference cosponsored by NSF, the Council on Environmental Quality, the Environmental Protection Agency, the Nuclear Regulatory Commission, and the Energy Research and Development Administration. The conference was carried out by Mitre Corporation in an effort to provide a forum for discussing the legal, social, environmental, and other public policy issues involved in nuclear waste management.

- *Solar Heating and Cooling: An Economic Assessment*, a report examining the economics of solar heating systems in 20 U.S. cities, using varying assumptions about the costs of the solar collectors.
- *Energy: Global Prospects 1985-2000. Report of the Workshop on Alternative Energy Strategies*, a report on an extensive effort by the Massachusetts Institute of Technology, involving 35 business, government, and academic leaders from 15 countries, to map plausible world energy futures to the end of the century.
- *Large-Scale Energy Planning Models: A Methodological Assessment*, a report by Stanford Research Institute describing five national energy planning models. It explains how they work, what they achieve, and the general policy context in which they are relevant.

## The Socioeconomic Effects of Science and Technology

The purpose of this group was to provide information useful in formulating Federal actions to improve the contribution of science and technology to the Nation. Studies were conducted to assess the impact of

science and technology on the U.S. economy and quality of life and to provide better measurements of the benefits and costs of science and technology. Projects included:

- The Relationship Between R&D and Returns from Technological Innovation, a colloquium of researchers, government officials, and industry representatives to review the implications of recent research findings for policy planning and research priorities.
- A workshop to identify and define the factors that govern the contribution technology makes to U.S. international competitive capabilities and to our socioeconomic development. The results of this project will be published in the final report, *Technology, Trade, and the U.S. Economy*, prepared by the National Academy of Engineering.
- An assessment by Oakridge Associates of the impact of mechanisms used to help workers adjust to technological change.
- A study by the National Bureau of Economic Research of the impact of multinational firms on technology and trade flows.

The projects described on these pages illustrate the nature and scope of work conducted and funded by NSF in the policy research and analysis area. A cumulative listing and brief abstract of the studies completed through the end of fiscal year 1977, together with ordering information for individual reports, is available (free of charge) from the National Science Foundation, Directorate for Scientific, Technological, and International Affairs, Division of Policy Research and Analysis, Washington, D.C. 20550.

### Science Resources Studies

The Foundation's program of science resources studies collects, interprets, analyzes, and disseminates data relating to the Nation's scientific and technological resources and activities. The main objective of the program is the development of factual data and analytical information to provide a basis for planning and policy formulation in the area of science and technology resources.

To carry out the science resources program, the Foundation supports two types of closely interrelated activities—collection of statistical data and analysis of resource information. Analysis is receiving increased emphasis; in fiscal year 1977 NSF initiated a new program of competitive awards specifically for science resource analytical studies. Studies funded included those on the responsiveness of the national technical manpower system to changes in levels of economic activity, occupational and skill mobility of Ph.D.'s, and factors affecting male and female participation in the scientific and technical labor force.

### Overall National R&D Resources

Information on the total national R&D expenditure is developed from surveys of the various sectors of the economy. Estimates for the current year are based on analyses of trends and factors pertinent to current funding patterns. These analyses showed that in 1977 total R&D spending within the United States is expected to reach \$40.8 billion, up 9 percent over 1976. In constant dollars, assuming a 5.5-percent inflation rate in 1977, the increase will be 3 percent. Most of this increase is expected to be the result of increased Federal R&D funding. After nearly a decade of decreases, Federal research and development should record in 1977 its second consecutive

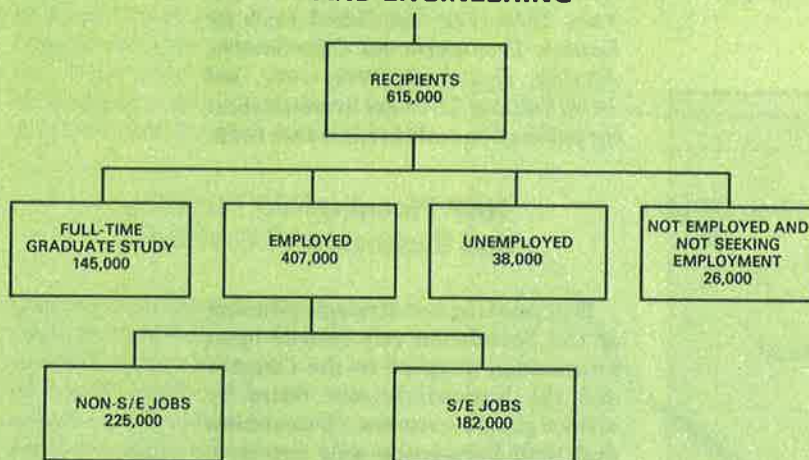
increase. During 1976, an estimated 542,000 scientists and engineers were employed in R&D activities in the United States. Although R&D professional employment has increased each year since 1972, the overall level is still below the 1969 peak of 557,000. These and other data are published in *National Patterns of R&D Resources: Funds and Manpower in the United States, 1953-1977*.

### Scientific and Technical Manpower

*Manpower Characteristics Systems.* Information on the employment, work activities, and professional characteristics of the U.S. scientific and engineering population is available from the Foundation's manpower characteristics system. The system consists of a series of surveys that develop information on the magnitude and characteristics of the U.S. science and engineering population and labor force. Several reports based on information generated by the components of the system were published this year, including *Characteristics of Doctoral Scientists and Engineers in the United States, 1975*. A report describing the characteristics of U.S. scientists and engineers for 1976 is in preparation for publication during fiscal year 1978. Also in preparation is a report on the employment, demographic, and professional characteristics of the approximately 600,000 individuals who received bachelor's degrees in science and engineering in 1974 or 1975. Data indicate that about half of those employed were engaged in scientific and engineering activities. Slightly more than 40 percent of these recent bachelor's degree recipients were pursuing graduate studies on either a full-time or part-time basis.

*Energy-Related Technical Personnel.* Current interest in scientific and technical personnel for energy-related activities arises from national recognition of the need to decrease reliance on

## FLOW OF 1974-75 BACCALAUREATE RECIPIENTS IN SCIENCE AND ENGINEERING



SOURCE: National Science Foundation

January 1978

those background skills needed for science activities by the time they complete high school.

### R&D Funding

*Industrial Research and Development.* Roughly 70 percent of all U.S. R&D funds are used by the industrial sector. Preliminary data indicate that total industrial R&D spending reached an estimated \$25.6 billion in 1976. When measured in constant dollars, the rise in industrial R&D expenditures was 3 percent. The Federal Government financed more than one-third of industrial R&D performance in 1976. However, even though Federal support of industrial R&D has been increasing since 1972, the proportion of all industrial R&D expenditures provided by the Federal Government has been steadily declining since 1969. Energy research and development in industry rose to \$1.6 billion in 1976, 13 percent over the 1975 figure, while research and development focused on pollution abatement remained essentially constant. Reports in the series *Research and Development in Industry* are published annually.

A special study of the magnitude of research and development in small companies and the problems these firms are encountering is currently in progress. Initial development of a comprehensive list of small R&D firms was completed in fiscal year 1977. This will be followed by a survey and interviews in 1978.

*Federal R&D Obligations.* Data based on the President's fiscal year 1978 budget request show Federal obligations for research and development of \$26.3 billion. When adjusted for inflation, the estimated total for 1978 appears to be only slightly more than 1977 and 15 percent lower than 1967, the peak year for Federal R&D funding in constant-dollar terms. When analyzed by functional areas, energy development and conversion shows greatest relative growth (17 percent) in 1978, with

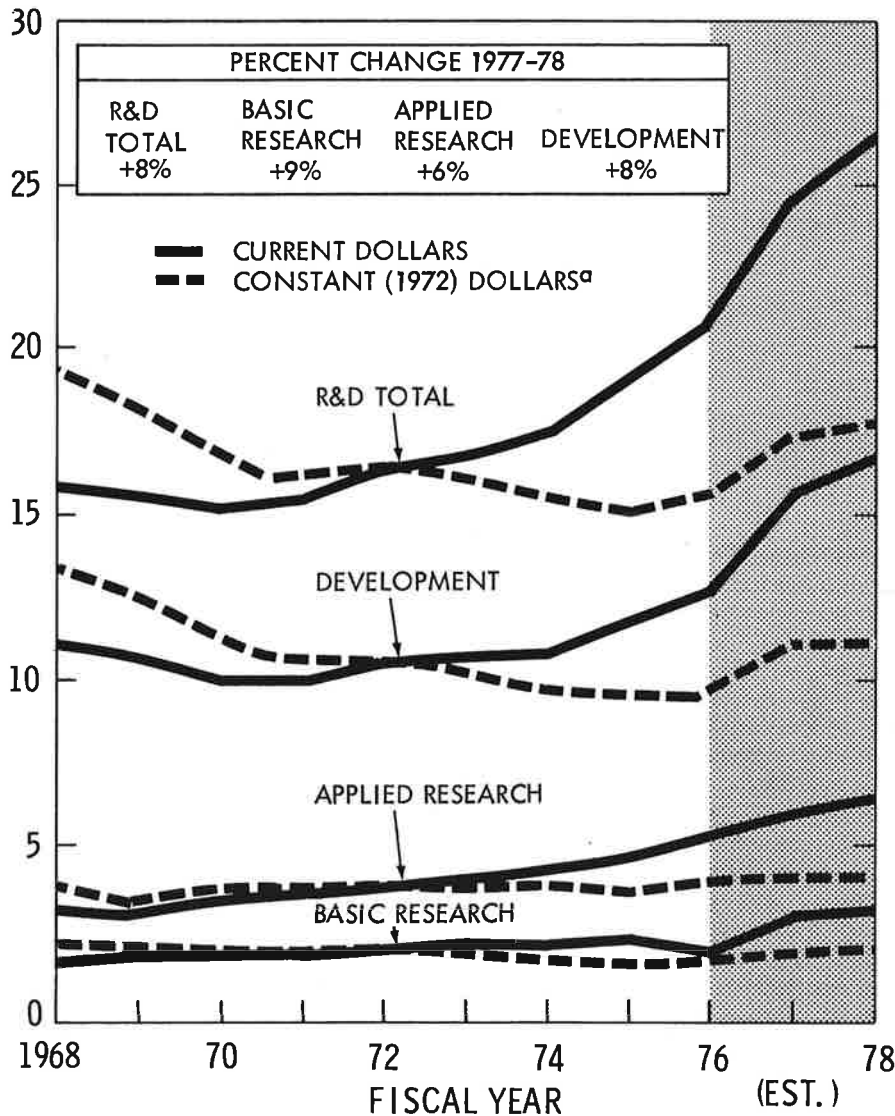
imported energy supplies. Beginning in 1974, the Foundation undertook a program of energy manpower studies to assess the impact on scientific and technical personnel of past energy developments and future options. During the past year, a report summarizing the findings of several recent studies was published in the series *Reviews of Data on Science Resources*. These studies found that 16 percent of all scientists and engineers in private industry are employed in energy-related work. While there appears to be no shortage of scientists and engineers for energy-related activities, there is evidence of a significant lack of mining, chemical, and petroleum engineers. Since 1975, however, the number of baccalaureate degrees in these fields has grown substantially, indicating that students are responding to the increased opportunities for employment. For any three projected 1985 energy-use scenarios, requirements for scientists and engineers are approximately identical, namely about 200,000. Preliminary supply projections indicate that there should be no difficulties in meeting these overall

requirements. The supply-demand relationship for individual occupations in energy-related work is now being developed.

*Women and Minorities in Science and Engineering.* Because of the changing roles of women and minorities in science and engineering, the Foundation is developing a statistical base for this component of the technical human resources system. A special analytical report, *Women and Minorities in Science and Engineering*, was published midway through fiscal year 1977. This report assesses the roles of women and minorities in science and engineering. It shows that although both women and minorities are underrepresented in science and engineering, the reasons for this underrepresentation differ. So do the prospects for the future. There is little difference between the science potential of young men and women at the end of high school. However, despite similar abilities, relatively fewer women than men enter careers in science. Also, a large fraction of women with degrees in science are not in the active labor force. Minorities, however, appear not to have developed

## Federal R&D obligations by character of work: FY 1968-78

(BILLIONS OF DOLLARS)



<sup>a</sup>Based on GNP implicit price deflator with estimates for fiscal years 1977 and 1978.

SOURCE: National Science Foundation

science and technology base (11 percent) second, and national defense (8 percent) third. Space and health show less growth in 1978 among leading

functional areas, and environment shows a leveling off. These and other data on characteristics of Federal R&D support were published in preliminary

form in the *Science Resources Highlights* series. Two reports, *An Analysis of Federal R&D Funding by Function, Fiscal Years 1969-1978* and *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years 1976, 1977, and 1978*, Volume XXVI, are in preparation for publication early in fiscal year 1978.

### NSF Planning and Evaluation

Policymaking and strategic planning at the Foundation rely heavily upon information supplied to the Director and the National Science Board by science planning studies. These studies deal with Foundation-wide concerns, as perceived by the Foundation itself, by the science community, by the Office of Management and Budget, and by the Congress. During the past year some of these studies were carried out by NSF staff; others were conducted outside the Foundation.

Among the issues considered was NSF involvement in research concerning renewable resources. Three small contracts were let for studies of techniques depicting the relevance of certain basic research to the needs of industrial technology. Finally, a contract was let for a study designed to assess current understanding of the research needs of State and local governments.

The program continued to define issues for the National Science Board's experiment with public participation in science policy. An important part of that experiment has been a series of regional public forums in which community, business, and educational leaders have met with members of the National Science Board to discuss research issues and opportunities. The first two forums were held in fiscal year 1977: in Seattle, Wash., on November 8, 1976, and in Dallas, Tex., on April 12, 1977.

A 2-year survey, funded by the program, of the future research role of universities was completed, resulting

n a widely recognized publication by Bruce Smith and Joseph Karlesky, *The State of Academic Science*, (New Rochelle, N.Y.: Change Magazine Press, 1977). The authors reported that the retrenchment in universities that has been occurring since the peak of Federal support for basic research in the late 1960's is likely to continue. Its impacts are being seen in an increasing stratification in university science, with widening differences in quality between the strong and weak departments as fewer institutions continue to provide broad coverage in science instruction and to perform innovative frontier research. A companion volume of essays on special topics will be published in December 1977.

Some of the activities initiated in fiscal year 1976 as a consequence of Congressional interest in NSF's peer review process were completed. *Perceptions of the National Science Foundation Peer Review Process: A Report on a Survey of NSF Reviewers and Applicants*, by Deborah Hensler, was published in December 1976. Funding was provided for a "phase two" of the National Academy of Sciences study describing some dynamics of the operation of the NSF peer review process. Finally, the studies initiated in response to the January 1976, *Report on NSF Peer Review of the House Subcommittee on Science Research and Technology* had reached the final draft stage by the end of the fiscal year.

Evaluation studies provide the Director of the Foundation with information on the effectiveness, results, and impacts of major NSF programs. They form the basis of his oversight responsibilities in these areas and provide groundwork for budgetary or policy decisions about program expansion, curtailment, or reorientation. They focus on program output, using criteria based on program objectives and policy concerns. Program evaluations are designed internally; they are often carried out by qualified contractors.

In 1977 evaluations of two major NSF programs were completed: the International Decade of Ocean Exploration (IDOE) and Science Information Activities.

In 1975, at the midpoint of the decade, NSF attempted to evaluate the progress that each IDOE project had made toward accomplishing objectives and to assess the degree to which results have contributed to goals of the decade. Progress was measured by oceanographers' comparison of the results obtained thus far with project objectives, along with an assessment of the amount of synthesis of individual findings that had taken place. Contributions to program goals were measured by assessments of the relevance of project objectives to program goals and the quality, uniqueness, and utility in application of the IDOE results. The evaluation concluded that the original program goals enumerated by the Vice President in 1969 would not be met by the end of the decade—a finding that was expected, given the broad nature of these goals.

Of the 12 projects evaluated, 4 had made substantial progress, 5 projects made some progress, and 3 projects had made little progress and are not likely to meet their original objectives by the end of the decade. Project results will be useful for future research and are already being used, as indicated by citations in publications. Applied utilization of results is small, and some of the projects are of questionable utility to the original goals. However, the validity of the applied research criterion is less applicable now in light of the strong basic research orientation of IDOE projects. The quality of the research is at least as good as similar NSF-supported work in the ocean sciences. Roughly half of the results are unique in that they could not have been achieved through the small grant support mechanism.

The Foundation has conducted Science Information Activities since 1950.

In 1977 it undertook an evaluation of the 1958-1972 program. Conclusions concerning changes in quantity and availability of information are: (1) *Publications and translations*—The quantity and availability of formally published scientific information was increased; (2) *Information systems*—This program contributed to the development of automated information systems, now operational in six disciplines at five universities and a major research institute. Systems sponsored in two other disciplines and at one other university are no longer operational on a regular basis; (3) *Research and studies*—The quantity of published research shows that Foundation-sponsored research projects have been as productive as other federally sponsored research and development; and (4) *Information Centers*—Many of the centers or depositories supported under this program have since been absorbed into other activities. The Smithsonian Science Information Exchange, which collects and distributes information on currently active Federal research projects, is the principal remaining center.

Conclusions concerning the usefulness of scientific information are: (1) *Publications and translations*—Sizable fractions of the supported publications have been used infrequently by American scientists; (2) *Information systems*—At universities that have an NSF-supported information system, most of the chemistry faculties reported that they used the system at least monthly and that the services were highly important to their work. These university systems, which are made available at little or no cost, have proven useful. Their use might not be so extensive if the services were priced at full cost; (3) *Research and studies*—Published articles resulting from this program were more likely to be cited by later authors than were other published articles in the field. This difference in the frequency of citation was observed both in the period soon after publication and in the period long after publication. It suggests that

information research has had both short-term and long-term impact on later research; and (4) *Information centers*—Government agencies have not

used the Smithsonian Science Information Exchange to the fullest extent possible. Its data bank is not considered sufficiently current or complete.

assessed in an independent evaluation to begin in fiscal year 1978.

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## Science Information Activities

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The science information program supports activities to make scientific and technical information more accessible, thereby more widely used. During 1977 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. During 1977 most of the basic information science research focused on improving the utility of information systems. Research at the Georgia Institute of Technology and the University of Maryland helped strengthen the theoretical foundations of information science by refining its basic concepts. Research at the Massachusetts Institute of Technology, Lehigh University, and the Illinois Institute of Technology Research Institute is expected to ease the problems of user access to on-line, science information retrieval systems. Also, joint research with the Foundation's computer science research program was continued on networking problems. In one project, some 20 academic institutions are involved in a large-scale simulator and gaining effort under the auspices of EDUCOM. In another jointly funded project, researchers at Stanford University are concluding analyses of the costs and benefits of computer communications networks.

### Access Improvement

The access improvement program supported projects on transfer of scientific information from originators to users. One such project continues to survey technical and organizational innovations in scientific and technical communication and to disseminate the results. Support was continued for projects of the University of North Carolina and the Council on Library Resources to develop national standards for library and information practices. A related project, managed by the National Federation of Abstracting and Indexing Services, continued cooperation between U.S. and European information services on standards for the exchange of machine-readable information.

Two new and related programs were launched in 1977. First, the staff of the access improvement program began using several computer-based information systems to increase their productivity and expertise in the use of computer-based systems and networks. Second, using one of these systems, the program initiated research on the use of computer conferencing and other forms of electronic information exchange. These will enhance communication among geographically scattered researchers. Projects were begun with teams of researchers organized by the University of Dayton, George Washington University, Innovative Systems Research, Inc., and Lehigh University. These projects will be

### User Requirements

The user requirements program continued to fund research designed to encourage scientists and engineers to use scientific and technical information more effectively. Among these projects, the Polytechnic Institute of New York made a longitudinal study of the relationships between the use of scientific and technical information and the productivity of engineers. The American Institute of Physics began an assessment of the use of communications satellite technology in searching computer-based bibliographic information files and in delivering scientific documents. Experiments initiated under the auspices of the Industrial Research Institute will assess innovations in the transfer of interdisciplinary information among scientists and engineers in industrial research laboratories. An award was made for Stanford Research Institute to evaluate an electronic alternative to the traditional paper-based dissemination of technical information to engineers. At Florida State University, researchers are measuring the impacts of on-line retrieval services on the information-seeking behavior of academic and industrial chemists. Also, researchers at the University of Kansas and the University of Michigan are studying the incorporation of computer-based information resources into engineering and science education programs.

### Management Studies and Coordination

Research on the costs and benefits of scientific and technical communication activities was continued. Four studies continued research on measurement of the volume and costs associated with the generation and transmission of scientific and technical information. These studies are being carried out at



New York University, Indiana University, King Research, Inc., and the National Commission on Libraries and Information Science. Results of these studies are providing the first comprehensive data on the scientific and technical communication enterprise in the United States. Other studies represent exploratory research on the measurement of the value of information. These include cost-benefit analyses of information centers by Purdue University and Metrics, Inc.; estimation of demand in relation to costs of library services by Case Western Reserve University and Kent State University; the scientists' perceptions of journals by King Research, Inc.; and estimation of demand for journals and other information services by Charles River Associates.

The Foundation also arranged for U.S. participation in a variety of cooperative international science information activities. These included bilateral exchanges with the Soviet Union, Egypt, and India; participation in nongovernmental programs, such as the meetings of the International Federation for Documentation and of the Abstracting Board and Committee on Scientific and Technical Data of the International Council of Scientific Unions; and intergovernmental activities of UNESCO and its UNISIST program. Continued support was provided for the Committee on International Scientific and Technical Information Programs of the National Academy of Sciences for review of international scientific and technical information programs.

applications in aircraft maintenance.

*Binational workshops and seminars.* These bring together small groups of leading scientists (normally 20 to 25) from the United States and another country to discuss the latest advances in a scientific discipline. Often the contacts established at these meetings lead to collaborative efforts. In some instances workshops are organized directly by NSF and its counterpart organization abroad to survey the state of knowledge in a preselected field of science and to stimulate closer cooperation between the two countries. A recent example is a food science seminar held under the U.S.-Japan Cooperative Science program.

The special foreign currency (SFC) programs also conduct the types of activities described above. The difference, however, is that no dollar funds are used. The program utilizes U.S.-owned foreign currencies in a few countries where the U.S. Treasury has declared U.S. holdings in excess of normal requirements. During fiscal year 1977 NSF made SFC awards in Egypt, India, Pakistan, Poland, and Tunisia for research and related scientific activities and for English translations of foreign scientific and technical literature. SFC grants may be awarded to U.S. institutions or to foreign institutions; however, in the latter case, a U.S. collaborating scientist must be actively involved in the project. SFC-funded projects provided unique opportunities for geological studies in Egypt, Tunisia, and Pakistan. In Egypt, scientists of Southern Methodist University collaborated on geophysical studies of heat flow and microearthquake activity near the Red Sea border. SFC funds were also used to assure adequate U.S. participation at two important international conferences in India, one on earthquake engineering, the other related to project MONEX, an international monsoon experiment.

Both India and Egypt are among ten countries with whom the United States has established Joint Com-

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## International Cooperative Scientific Activities

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Under the Foundation's international programs, U.S. scientists participate in activities with colleagues in foreign countries. Many of these cooperative activities take place under formal agreements between the United States and other countries. During fiscal year 1977, NSF supported scientific projects with 26 countries through bilateral science and technology agreements, joint commissions for scientific or economic cooperation, interacademy exchanges of scientists, and special foreign currency programs. Typical activities conducted under these programs included:

*Cooperative research projects.* A group of U.S. scientists collaborates with a research group abroad on a problem of mutual interest. The work is usually performed simultaneously in both countries and normally includes exchanges of data and staff and sharing of facilities and costs. One example is

the joint study of the joboba plant by U.S. and Mexican scientists. This plant, which is native to Mexico and the Southwestern United States, produces an oil that is a potential substitute for sperm whale oil.

*Scientific visits.* These include visits of short and long duration. U.S. scientists make short visits to foreign laboratories, mainly to exchange information or to develop cooperative research projects. The purpose of long-term visits, which usually span 6 to 12 months, is to perform research at institutes abroad where facilities are unique or special expertise is available. One project on metal fatigue was conducted by a U.S. scientist from the University of Cincinnati at the University of Melbourne, Australia, where excellent metal-testing facilities are available. This project produced improved theories on crack growth delay in metals, which could have significant

missions to enhance political, economic, cultural, and scientific relations. Under the Joint Commission in Egypt, NSF assumed the responsibility of helping establish a biomedical engineering department at

Cairo University. Under the U.S.-U.S.S.R. Joint Commission on Scientific and Technical Cooperation, NSF funds the activities of 7 out of 12 working groups and provides overall coordination and administrative sup-

port for the program. The 5-year agreement with the Soviet Union was renewed in 1977. Changes in emphasis accepted by the Soviet Union and the United States will result in increased support for projects in electrometallurgy and physics while reducing the joint efforts in microbiology, chemical catalysis, and science and technology information.

In addition to these programs under formal intergovernmental agreements, NSF maintained informal contacts with sister organizations in other countries, usually national research councils or ministries for science and technology. Such informal arrangements resulted in cooperative activities in an additional 28 countries. For the most part the same activities—cooperative research projects, scientific visits, and joint seminars—were employed under these informal programs, and costs and facilities were shared by the United States and the cooperating country. Major regional emphasis during the year has been on joint activities with countries in Latin America and East Asia. The University of Washington and Kasetsart University in Thailand began a joint study with economic as well as scientific implications. The project will develop system models for the study of forest land utilization. The results of this study should contribute to better management of forest land in Southeast Asia and in other regions of the world.

These informal arrangements are not limited to less advanced countries. The Foundation has been responsive to congressional suggestions to help restore interactions with our traditional scientific partners, the advanced countries of Western Europe. As part of a new effort, NSF collaborated with the Federal German Ministry for Research and Technology in organizing an international workshop on technological innovation. Scientists, engineers, and industrialists from the United States,



**Special Foreign Currency project.** Egyptian and American scientists (from Southern Methodist University) measure borehole temperatures in the Abu Dabbab Mine in the eastern Egyptian Desert to study heat flow in the continental crust. The region around the Red Sea is drawing scientific interest as a possible embryonic spreading center splitting Africa from Arabia. (Photo by Paul Morgan, SMU)

Western Europe, and Japan participated.

The exchange of scientific delegations between the United States and the People's Republic of China (PRC) continued into its fifth year despite the absence of formal diplomatic relations between the two countries. The National Academy of Sciences' Committee for Scholarly Communication with the PRC, representing the United States, negotiates these exchanges directly with the Scientific and Technical Association of China and arranges the scientific visits. NSF contributed a major share of the Committee's expenses. During fiscal year 1977, three U.S. delegations of experts in steroid chemistry and biochemistry, vegetable cropping systems, and cancer research visited China. A fourth visit by a group

representing the Committee itself was to review the program with the Chinese and present proposals for the following year. The PRC sent five delegations to the United States in astronomy, chemistry, meteorology, hematite ore dressing, and mineral resources drilling techniques.

Under a special program funded by the Agency for International Development, scientists and engineers in economic development (SEED), NSF awarded grants for research or teaching to U.S. scientists to work in 17 different countries of Asia, Africa, and Latin America. Among the subjects studied by the U.S. scientists and their foreign colleagues were pollution in the Aegean Sea, wilting potato crops in Brazil, new sources of food and medicine in the Philippines, and economic development in Korea.

The Foundation continued to provide primary support for U.S. participation in the International Council of Scientific Unions (ICSU) and many of its adherent scientific unions. NSF awards to the National Academy of Sciences included the payment of U.S. dues as well as the support of national committees responsible for coordinating U.S. participation. The National Academy of Sciences was also the recipient of an award for the U.S. membership in the International Institute for Applied Systems Analysis. This institute, located near Vienna, Austria, includes representatives of industrialized nations of Eastern and Western Europe, the United States, Canada, and Japan. It studies such problems of global significance as energy, environment, and urbanization.



## Appendix A

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## Appendix B

### *Patents and Inventions Resulting from Activities Supported by the National Science Foundation*

During fiscal year 1977, the Foundation received 123 invention disclosures and made rights determinations in 59 inventions. The determinations, made in accordance with NSF Patent Regulations, included decisions to dedicate the invention to the public through publication in 9 cases, to transfer rights to other interested Government agencies in 6 cases, and to permit retention of rights by the grantee or inventor in 44 instances. At the end of the fiscal year NSF had entered into 4 additional

Institutional Patent Agreements for a total of 17, under which 8 inventions were selected for exploitation. Licenses were received by the Foundation under 7 patents and 53 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
3,939,350	A New Fluorescent Immunoassay	Stanford University
3,959,078	Enzyme Immobilization with a Thermochemical-Photochemical Bifunctional Agent	Midwest Research Institute
3,967,931	Chamber Aerosol Detector	Arizona State University
3,981,626	Down Hole Pump and Method of Deep Well Pumping	Sundstrand Corp.
3,983,033	Pollutant Removal Process	Massachusetts Institute of Technology
3,991,764	Plasma Arc Scalpel	Purdue University
3,992,424	Synthesis of Trifluoromethyl Substituted Compounds	Massachusetts Institute of Technology
3,993,550	Photochlorination of Alkanols (Lysine Synthesis)	Pennsylvania State University
4,000,466	A Technique for Time Interval Measurements	Iowa State University
4,004,980	Enzyme Entrapment with Cellulose Acetate Formulations	Purdue Research Foundation
4,007,009	Chemical Analysis of Ions Incorporated in Lattices Using Coherent Excitation Sources	Wisconsin Alumni Research Foundation
4,007,211	Oxidative Decarboxylation of Carboxylic Acids	Wisconsin Alumni Research Foundation
4,011,747	Chirp Waveform Generation by Scattering of Acoustic Waves	Stanford University
4,013,477	A Method for Fabricating a Conductive Polycrystalline B <sup>2+</sup> Al <sub>2</sub> O <sub>3</sub> Ceramic by a Rapid Single-Stage Sintering Process	University of Utah
4,019,652	Fluid Delivery and Mixing Systems	Massachusetts Institute of Technology
4,021,933	Student-Programmable Educational Instrumentation Device	Health Systems Management Corporation
4,034,966	Method and Apparatus for Mixing Particles	Massachusetts Institute of Technology

- 4,035,550 Fiber Reinforced Composite of High Fracture Toughness
- 4,036,693 Treatment of Cell Culture Microcarriers
- 4,042,196 Method and Apparatus for Triggering a Substantial Change in Earth Characteristics and Measuring Earth Changes

Massachusetts Institute  
of Technology  
University of Oregon  
Cornell Research  
Foundation

## Appendix C

## Financial Report for Fiscal Year 1977

(In Thousands of Dollars)

**Research and Related Activities Appropriation  
Fund Availability**

Fiscal year 1977 appropriation.....	\$712,311	
Unobligated balance brought forward.....	5,315	
Adjustment to prior year accounts.....	3,397	
Fiscal year 1977 availability .....		<u>\$721,023</u>

**Obligations**

## Mathematical and physical sciences, and engineering:

Mathematical sciences.....	\$20,061
Computer research.....	15,790
Physics.....	53,995
Chemistry.....	40,226
Engineering.....	41,771
Materials research.....	52,576

Subtotal, mathematical and physical sciences, and  
engineering .....\$224,419

## Astronomical, atmospheric, earth, and ocean sciences:

Astronomical sciences.....	\$52,179
Atmospheric sciences.....	49,131
Earth sciences.....	29,070
Ocean sciences.....	53,227
Arctic research program.....	4,623

Subtotal, astronomical, atmospheric, earth, and ocean  
sciences .....\$188,230

## U.S. Antarctic program .....

\$45,295

## Biological, behavioral, and social sciences:

Physiology, cellular, and molecular biology.....	\$51,342
Behavioral and neural sciences.....	23,806
Environmental biology.....	30,174
Social sciences.....	21,285

## Subtotal, biological, behavioral, and social sciences .....

\$126,607

## Research applied to national needs:

Resources.....	\$9,964
Environment.....	24,103
Productivity.....	22,139
Intergovernmental science and R&D incentives.....	6,153
Exploratory research and technology assessment.....	1,380

## Subtotal, research applied to national needs .....

\$63,739<sup>1</sup><sup>1</sup> Includes \$1,380 for technology assessment in fiscal year 1977.

<b>Scientific, technological, and international affairs:</b>	
International cooperative scientific activities .....	\$8,486
Science information activities .....	4,538
Science assessment, policy, and planning.....	<u>6,258</u>
Subtotal, scientific, technological, and international affairs	<u>\$19,282<sup>2</sup></u>
Program development and management .....	<u>\$45,530</u>
Subtotal, obligations.....	<u>\$713,102</u>
Unobligated balance carried forward .....	\$7,216
Unobligated balance lapsing .....	<u>705</u>
Total, fiscal year 1977 availability for research and related activities .....	<u><u>\$721,023</u></u>

**Science Education Activities Appropriation  
Fund Availability**

Fiscal year 1977 appropriation.....	\$59,000
Unobligated balance brought forward.....	6,014
Deferrals brought forward.....	10,000
Adjustment to prior year accounts.....	<u>206</u>
Fiscal year 1977 availability .....	<u><u>\$75,220</u></u>

**Obligations**

<b>Science education activities:</b>	
Scientific personnel improvement .....	\$30,913
Science education resources improvement.....	28,196
Science education development and research.....	11,067
Science and society .....	<u>4,088</u>
Subtotal, obligations.....	<u>\$74,264</u>
Unobligated balance carried forward .....	\$758
Unobligated balance lapsing .....	<u>198</u>
Total, fiscal year 1977 availability for science education activities .....	<u><u>\$75,220</u></u>

**Special Foreign Currency Appropriation  
Fund Availability**

Fiscal year 1977 appropriation.....	\$4,600
Unobligated balance brought forward.....	384
Adjustment to prior year accounts.....	<u>3</u>
Fiscal year 1977 availability .....	<u><u>\$4,987</u></u>

**Obligations**

<b>Special foreign currency program:</b>	
Research and related activities .....	\$3,960
Science information .....	<u>444</u>

<sup>2</sup> Excludes \$1,380 for technology assessment in fiscal year 1977.

Subtotal, obligations .....		<u>\$4,404</u>
Unobligated balance carried forward .....		\$534
Unobligated balance lapsing .....		<u>49</u>
Total, fiscal year 1977 availability for special foreign currency program.....		<u><u>\$4,987</u></u>
<b>Trust Fund</b>		
<b>Fund Availability</b>		
Unobligated balance brought forward.....	\$1,613	
Receipts from non-Federal sources .....	<u>6,841</u>	
Fiscal year 1977 availability .....		<u><u>\$8,454</u></u>
<b>Obligations</b>		
Astronomical, atmospheric, earth, and ocean sciences activity (ocean sediment coring program).....	\$4,664	
Gifts and donations.....	<u>5</u>	
Subtotal, obligations.....		<u>\$4,669</u>
Unobligated balance carried forward .....		<u>\$3,785</u>
Total, fiscal year 1977 availability for trust fund .....		<u><u>\$8,454</u></u>

SOURCES: Fiscal Year 1979 Revised Supplementary Budget  
Schedules to the Office of Management and Budget.  
Fiscal Year 1979 Budget to Congress—Justification of  
Estimates of Appropriations.



## Appendix D

### National Research Centers Contractors

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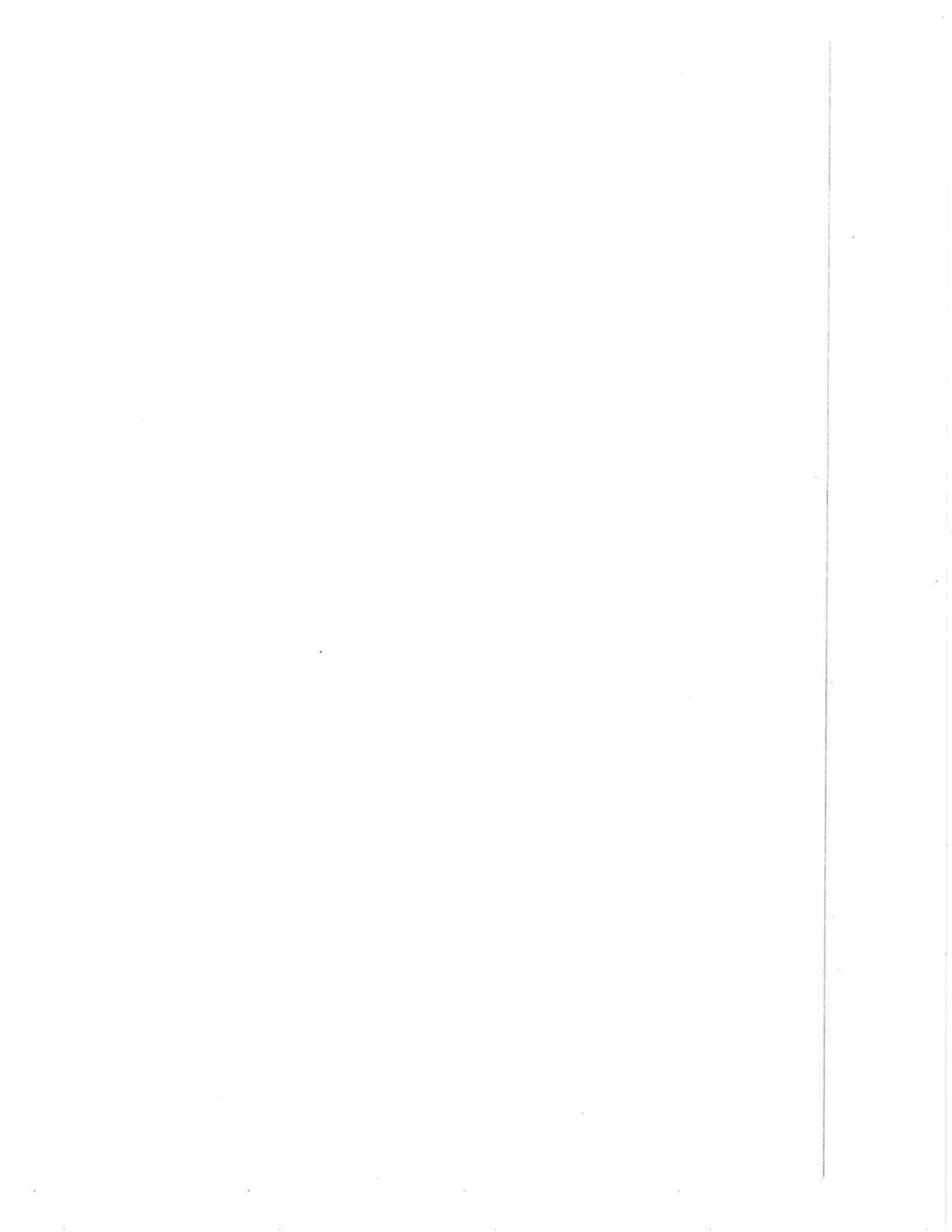
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