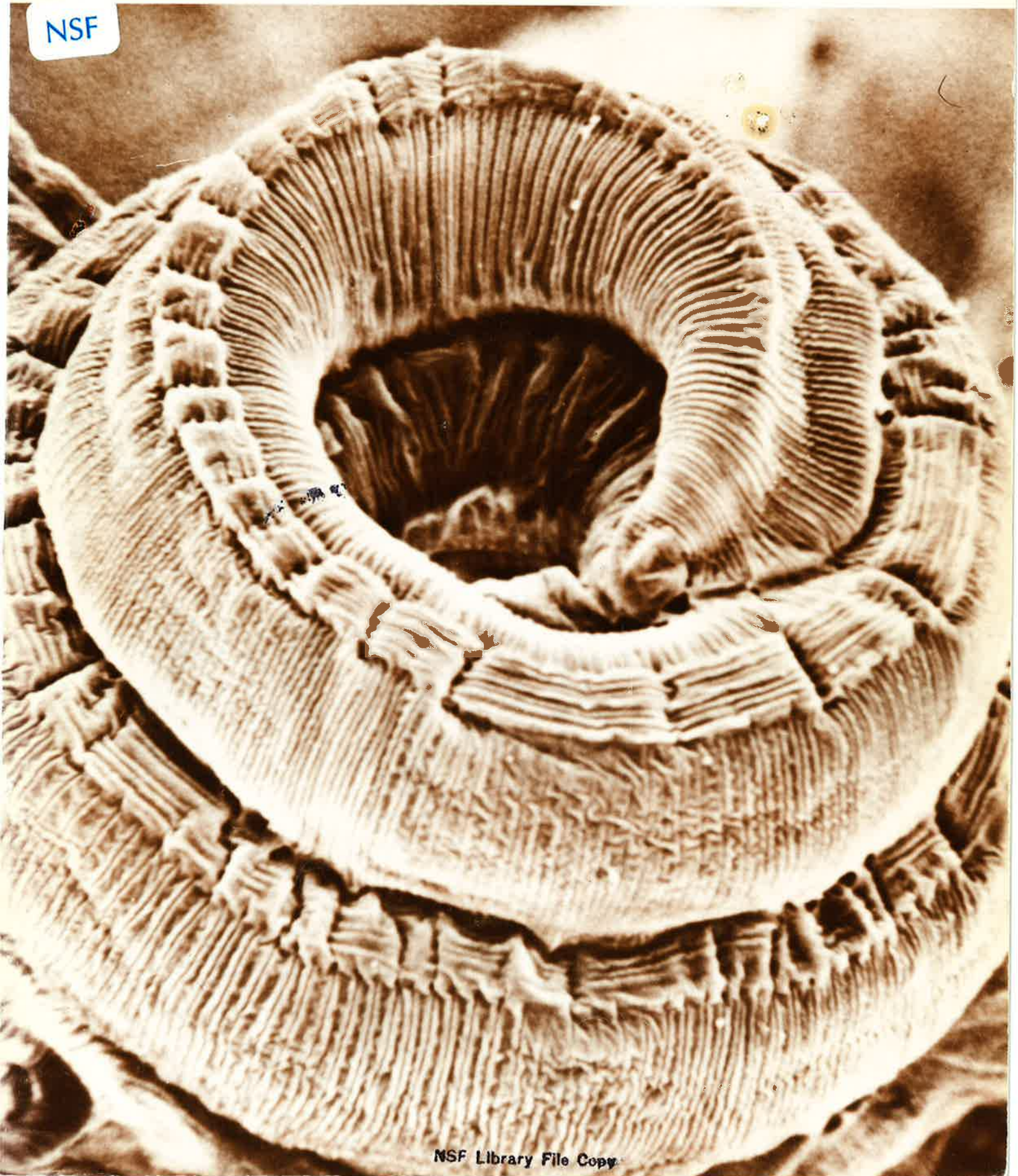


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National Science Foundation Annual Report 1984

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About the National Science Foundation

The National Science Foundation is an independent federal agency created by the National Science Foundation Act of 1950 (P.L. 81-507). Its aim is to promote and advance scientific progress in the United States. The idea of such a foundation was an outgrowth of the important contributions made by science and technology during World War II. From those first days, NSF has had a unique place in the federal government: It is responsible for the overall health of science across all disciplines. In contrast, other agencies support research focused on specific missions.

NSF funds research in all fields of science and engineering. It does this through grants and contracts to more than 2,000 colleges, universities, and other research institutions in all parts of the United States. The Foundation accounts for about 28 percent of fed-

eral support to academic institutions for basic research.

NSF receives more than 27,000 proposals each year for research and graduate fellowships and makes more than 12,000 awards. These go to universities, colleges, academic consortia, nonprofit institutions, and small businesses. The agency operates no laboratories itself but does support National Research Centers, certain oceanographic vessels, and Antarctic research stations. The Foundation also aids cooperative research between universities and industry and U.S. participation in international scientific efforts.

NSF is structured much like a university, with grant-making divisions for the various disciplines and fields of science and engineering. The Foundation's staff is helped by advisors, primarily from the scientific com-

munity, who serve on formal committees or as ad hoc reviewers of research proposals. This advisory system, which focuses on both program direction and specific proposals, involves more than 50,000 scientists and engineers a year. NSF staff members who are experts in a certain field or area make final award decisions; applicants get verbatim unsigned copies of peer reviews and can appeal those decisions.

Awardees are wholly responsible for doing their research and preparing the results for publication. Thus the Foundation does not assume responsibility for such findings or their interpretation.

NSF welcomes proposals on behalf of all qualified scientists and engineers and strongly encourages women, minorities, and the handicapped to compete fully in its programs.



National Science Foundation (U.S.)

Thirty-Fourth Annual Report for Fiscal Year 1984

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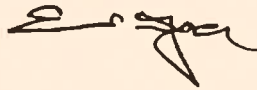
Letter of Transmittal

Washington, D.C.

DEAR MR. PRESIDENT :

I have the honor to transmit herewith the Annual Report for Fiscal Year 1984 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, appearing to read "E. Bloch", with a stylized flourish at the end.

Erich Bloch
Director, National Science Foundation

*The Honorable
The President of the United States*

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A Growing Partnership



ERICH BLOCH
Director

As we look back on the Foundation's activities in fiscal year 1984, a key theme is the interdependence and overlapping interests of many NSF programs. This reflects a basic change in the nature of science and engineering as our understanding of fundamental phenomena grows. Increasingly the lines are blurred between science and engineering, between the various disciplines, and between established and emerging fields. Effective research requires cooperation between universities, industry, and government; between nations; and between individual researchers or small teams. Mutual effort is also needed in large, capital-intensive projects involving many investigators from a variety of fields working over several years. Examples here are NSF's Ocean Drilling Program and the large research projects we support in the arctic and antarctic regions.

The chapters that follow highlight research supported by NSF last year, and much of it is indeed interactive and interdependent. But there are other recent activities to note as well:

—First, we have reinforced the role of the

individual researcher with the program known as Presidential Young Investigators. This program addresses the brightest young faculty, chosen solely for their research promise. The objective here is to attract and retain these people on university faculties. The emphasis is on engineering and the physical sciences, where shortages are greatest.

—We are launching several Engineering Research Centers, with more to be added in the future. Each will be focused on a major interdisciplinary area of interest to both industrial and academic researchers. Each center will attract—and require the cooperation of—researchers from many scientific and engineering disciplines, including members of the behavioral sciences. The centers will be located on university campuses, to promote strong links between research and education. Engineers and scientists from industry are expected to participate, to help focus activities on their needs.

—We have started a major push to stimulate and

coordinate research in topics related to biotechnology, an area in which the United States is strong — yet vulnerable to foreign competition.

- To remedy a problem of long standing, we have increased spending on research equipment and instrumentation sharply. We also have launched a large-scale effort to make access to advanced computing resources (supercomputers) available to university researchers as never before. To do the latter, we have set up an Office of Advanced Scientific Computing.
- Internally, we put more emphasis on certain program areas last year by creating new divisions, or separating earlier organizations. Thus we have split Mathematics and Computer Science into two divisions, and we created Cellular Biosciences and Molecular Biosciences from what was formerly Physiology, Cellular and Molecular Biology. We also have begun to rebuild our science and engineering education efforts.

Challenges, Responsibilities—and Partnerships

We are pleased with the progress of American research and technology and the role NSF has played in promoting that progress. However, we continue to see major challenges.

Today the United States faces international economic competition of unprecedented intensity. We can meet this challenge only if we understand the proper role of science and technology and make it work for us.

We face competition in research and development from other industrialized nations, and increasingly we will also have to expect significant competition from emerging regions as well.

Another challenge is that the complexity of technology is increasing at a more rapid rate than before—for products, for manufacturing processes, and for research itself. As the whole endeavor gets more complicated, the necessary skill levels become higher and many times more specialized, thus placing additional strain on our educational system.

So how do we meet the challenges? I say together, for today there is a much clearer view that a true partnership in support of science and engineering is necessary. Each partner has a stake in the outcome, and each should have a fairly well-defined role in providing certain kinds of support.

The partners are federal, state, and local governments, industry, and universities. The *federal*

government shares with industry the principal responsibility for supporting basic research. But as we move along the continuum from basic research to development, the proper role of the national government declines.

The second major player in science and engineering is *state and local government*. Together they bear principal responsibility for primary and secondary education, although federal programs may provide stimulation, some leadership, and specialized assistance.

Industry is the third major player. There is a clear recognition of industry's dominant role in development funding, but industry also has a major role in supporting basic research. Among the new approaches here is the rise in cooperative research arrangements. They increase the number of players dramatically and reduce costs without unduly affecting market competition.

Cooperative research efforts are also an example of closer ties between industry and *universities*, the fourth major partner. More and more, industry is joining with federal and often with state government to support university research in problems of interest to both industrial and academic researchers. Joint centers have emerged in such areas as welding, polymers, robotics, and computer graphics, to name just a few.

Twenty cooperative research centers launched by NSF now get most of their support from more than 200 private companies. They also involve 250 university faculty members, 30 postdoctoral scientists and engineers, 300 graduate students, and 40 undergraduates, along with 200-plus advisers and about 400 project monitors from industry.

Moving Ahead

The challenges we face are tough ones, to be sure. But this vast and varied nation has often faced great problems with a spirit of great energy and creativity. I like to think that the National Science Foundation is a part of that spirit.

We will continue to promote scientific inquiry, and we remain committed to the goals set forth in the 1950 legislation that created this agency: "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense. . . ." In the coming years we will work to do even better what the Foundation has always done well: support science, engineering, and education so that the nation may benefit.



Astronomical, Atmospheric, Earth, and Ocean Sciences



These NSF programs support research that adds to our knowledge of the natural environment on earth and in space. The domain of these sciences includes all matter beyond the earth, extending from the immediate environs of the solar system to the farthest limits of the observable universe. The programs also focus on ocean basins and the innermost crust of the earth, and they help scientists study mineral and fossil fuel resources, earthquakes and volcanic eruptions, and extreme weather conditions.

In 1984, ground-based and theoretical astronomy were supported through five grant programs to more than 140 universities, plus funding for three National Astronomy Centers. Far-reaching scientific advances include these:

- High-resolution radio maps—made by the Very Large Array and other telescopes through the technique of very long baseline interferometry—display unprecedented detail in the cores of the Milky Way and other galaxies. The maps reveal surprising similarities in those cores, such as the probable presence of supermassive, gas-accreting black holes.
- The use of sensitive electronic detectors and image-processing techniques (such as speckle interferometry, discussed later) is being extended from the optical region to other regions of the spectrum. These include the infrared, where cool, low-mass stars have been discovered as a result.

- Detailed analysis of starlight has confirmed the existence of solar-type phenomena, such as spots, on other stars.

Atmospheric science combines knowledge of physics, chemistry, mathematics, and other sciences to improve our understanding of the earth's atmosphere—from the planet's surface to outer space. Through seven grant programs and support of the National Center for Atmospheric Research (NCAR) and the Upper Atmospheric Facilities (UAF) program, the Foundation aided basic atmospheric research on a wide range of subjects in fiscal year 1984. NSF also continues to be the chief supporter of

academic research in the atmospheric sciences.

In fiscal year 1984, atmospheric scientists emphasized these activities:

- Planning, observations, analyses, and expanded instrument development for atmospheric chemistry research and for mesoscale phenomena (those 10 to 100 kilometers in spatial extent).
- Climate studies on interaction between the atmosphere and the oceans, especially conditions in the Pacific that influence U.S. climate.
- Early development of a prototype, interactive, computing network to

Table 1
Astronomical, Atmospheric, Earth, and Ocean Sciences
Fiscal Years 1983 and 1984

(Dollars in Millions)

	Fiscal Year 1983		Fiscal Year 1984	
	Number of Awards	Amount	Number of Awards	Amount
Astronomical Scis., Nat'l.				
Research Centers	240	\$ 62.72	287	\$ 77.18
Atmospheric Sciences, Nat'l.				
Research Centers	519	75.51	540	88.02
Earth Sciences	624	34.85	629	41.31
Ocean Sciences	710	102.53	673	114.28
Arctic Research	68	6.22	67	7.26
Subtotal	2,161	\$281.83	2,196	\$328.05
Adjustment to Internat'l Awards	—	-1.03*	—	—
Total	2,161	\$280.80	2,196	\$328.05

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.
SOURCE: Fiscal Years 1985 and 1986 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) and NSF accounting records.

link universities to NCAR's databases and computing capabilities.

- Acquiring a mass storage system for NCAR's computing facility.

NSF support of research in the earth sciences has improved our understanding of problems ranging from why major life forms suddenly die out to how, why, and when diamonds form. In the past year, researchers embarked on major new projects to unravel the complexities of the continental lithosphere (the solid part of the earth). The techniques and approaches being used include networks of seismometers to help define the structure of the earth's deep crust and upper mantle; deep drill holes at critical locations on the continents; and geochemical and petrologic studies of crustal and mantle rocks brought to the surface through volcanism, folding and faulting at plate margins, and deep drilling.

Along with these studies on the lithosphere, NSF has funded research on atmospheric evolution in the geologic past (through the study of fluid inclusion in minerals); on the history of the earth's magnetism and how some fossil species used it for their own benefit; on very primitive life forms (as old as 3.5 billion years); and on using radioactive nuclides of uranium to study the evolution of lava from geologically recent volcanoes.

Oceanography continues to be a rapidly developing field characterized by

dynamic boundaries with related disciplines and the continuing need for international cooperation. Although general-purpose research vessels are still the backbone of ocean research, scientists also study global ocean processes with satellites, acoustic and optic remote sensors, remote underwater vehicles, manned submersibles, a modern drillship, aircraft, instrumented buoys, and powerful computers. Large instrumentation and equipment are critical to ocean scientists.

This chapter describes research on the 1982-83 El Niño phenomenon—a prime example of cross-disciplinary and international work on major ocean problems.

The arctic research program managed by NSF supports research in the atmospheric, earth, and biological sciences and in glaciology and oceanography. The program often targets complex scientific questions that require the coordinated efforts of researchers in several disciplines over several years. Examples of recent projects include studies of air, ice, and sea interactions, ice-core drilling to the bottom of the Greenland ice sheet for studies of past climates, and evaluation of natural and artificial disturbances of tundra. Oceanographers and marine biologists have also focused on the extraordinary biotic productivity of the northern Bering and Chukchi Seas.

has revealed earthlike features. The light from some stars shows evidence of surface activity similar to that observed on the sun. The strange object in the center of our galaxy may have parallels in the mysterious engines driving energetic processes seen in quasars and some galaxies. Only by understanding the evolution of stars and galaxies can we learn about our ultimate origins and fate.

NSF funds studies of the composition, structure, and evolution of the sun, solar system, stars, interstellar medium, and galaxies, along with new instrumentation and computing facilities at universities and other institutions. In addition, three National Astronomy Centers offer first-class observing facilities in the optical, infrared, and radio regions of the spectrum for astronomers from across the country.

Infrared Speckle Interferometry

Atmospheric turbulence that makes the stars twinkle is the optical astronomer's nemesis. Although visibility of the faintest object detectable with a telescope is limited only by the instrument's aperture, the resolution—or ability to see detail—is affected by the size of the typical air cell passing in front of the telescope. The continuous motion of these air cells causes the image of a point source of light to blur and dance about. Each wavefront of light from the source is broken up into a pattern of light and darkness called speckle, much like the shadows seen in a rippling pond.

Direct observation of stellar surfaces other than our sun's and of the separation of very close binary stars was impossible until around 1970, when a technique called speckle interferometry emerged. A typical exposure time in astronomical photography is several minutes, more than enough to wash out the fine details glimpsed by the eye in moments of extreme atmospheric steadiness. Exposures of about one-hundredth of a second were found to contain all the detail theoretically expected for a telescope's aperture. Such short exposures would pre-

Astronomical Sciences

During the past two decades, there has been unprecedented discovery and excitement in astronomy; they stem from our newfound ability to explore the entire spectrum, from radio waves to gamma rays. Observations in all these regions are essential to better understanding of the many objects and phenomena in the universe.

To bring order out of this chaos of diversity, astronomers continually map

and classify objects ranging from asteroids in our solar system to the farthest galaxies. Nearby bodies are studied more easily than distant ones, while variety, including differences caused by age, increases with distance. Comparison of close and distant objects helps us understand the nature of the latter, the role of the former, and the scale and evolution of the cosmos.

Study of the surfaces of other planets

clude observation of all but the brightest objects, except for two recent developments: photoelectric image intensification and computerized image processing. In optical speckle work, an instrument called a microdensitometer scans ultra-short photographs of electronically intensified images; a computer, compensating for the motion of the atmosphere, then combines the scans.

Speckle interferometry was first applied to infrared work about three years ago by Robert Howell, Donald McCarthy, and Frank Low at the University of Arizona's Steward Observatory. Low was one of the founders of infrared astronomy in the 1960s, when sufficiently sensitive detectors for it became available. All three astronomers were pioneers in applying multiaperture interferometry to infrared observations during the 1970s. Their use of infrared speckle interferometry (with the 2.3-meter telescope at the Steward Observatory and the four-meter telescope at Kitt Peak National Observatory) has resulted in the resolution of 15 previously undetected companions of nearby stars.

The existence of most of these cool, low-mass objects had already been inferred from their gravitational influence on the motion of their brighter partners. Direct observation of these companion stars makes it possible to determine their masses and luminosities—quantities es-

sential to understanding the evolution of cool stars. Other objects being observed with the technique are newborn stars; circumstellar dust shells, and active galactic nuclei.

Starspots Mapped

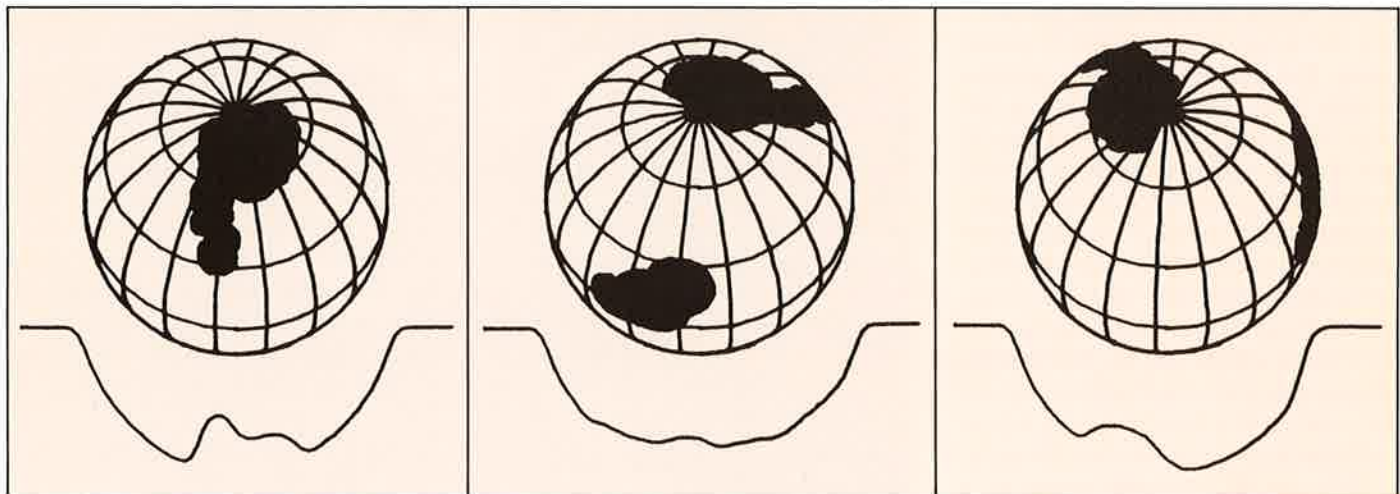
The sun is the only star whose surface we can see directly. Study of that surface has yielded much information about features that presumably are present in most stars, such as ionized gas eruptions, magnetic fields, and convective gas motions. Other stars appear only as point sources of light to telescopes other than interferometers. However, scientists have found that some variations in the brightness of those stars are like the variations produced by the stellar analogs to sunspots.

In stars cooler than the sun, convection is an even more important determinant of the star's outer structure. Nearly all theoretical models of stellar and solar magnetic dynamos couple convection with rotation and the twisting of magnetic field lines. Solar activity, such as sunspots and flares, is known to be controlled mainly by magnetism. Stars that can efficiently convert their mechanical energy of convection and rotation into magnetic energy are likely to display active phenomena even more pronounced than the sun's.

One type of star that has a surplus of both convection and spin is named after its prototype, RS Canum Venaticorum (CVn). An RS CVn star designated HR 1099 has been found to manifest not only brightness variations associated with starspots but changes in its spectrum as well. Typically, a stellar spectrum is crossed by dark absorption lines at wavelengths characteristic of the type of atoms in the star's atmosphere. If the star has a fast rotation rate, these lines are broadened by the Doppler effect (light absorbed from the hemisphere spinning toward the observer is shifted toward bluer wavelengths, light from the receding hemisphere toward the red). For HR 1099, the spectral lines show a small deficiency of absorption oscillating within each line, just the effect that would be caused by large spots on a rotating stellar surface.

Two astronomers at Lick Observatory, University of California at Santa Cruz, realized that these variations in spectral lines could be used to map the surface of HR 1099. Stephen Vogt and Donald Penrod combined spectrograms taken with Lick's three-meter telescope at different phases of the 2.8-day rotation. Allowing for the foreshortening caused by tilt of the star's spin axis, they were able to model the starspots so well that they could make a computer-generated movie of the rotating star. The starspots, al-

Starspots. Surface features of the star HR 1099, seen in computer-generated images and in these frames from a movie made of the rotating star. Spectral line below each image revealed key details. (Art from NSF magazine *Mosaic*, vol. 14, no. 6)



though vastly larger, are similar to sunspots in shape and in showing evolution and poleward migration. Our picture of the sun's place in the cosmos will become increasingly clear as new techniques like this promote the parallel study of the sun and its stellar neighbors.

The Galactic Center

The center of our galaxy has long been of extreme interest to astronomers. Some 30,000 light-years distant in the constellation Sagittarius, our galactic center is completely hidden from optical telescopes by interstellar clouds of gas and dust. However, radio waves pass unhindered through these clouds, and maps made at such wavelengths have revealed our galaxy to be of a spiral type quite common in the universe. The radio structure of our galaxy can be studied in much greater detail than that of galaxies millions of light-years away, and there have been great advances in this area with the Very Large Array (VLA) telescope of the National Radio Astronomy Observatory (NRAO).

Although the center of our galaxy does not display the spectacular activity of some galaxies and quasars, many intriguing features hint at similarities in nature and evolution. Large-scale expansion of neutral gas suggests that an explosive event occurred in that center about 10 million years ago. One object in the area appears to be a supernova remnant. Within the inner 10 light-years lies a three-armed spiral of ionized gas swirling about and falling toward a central point. The source of the ionizing photons is most likely a cluster of very young, hot stars. According to the radio spectrum of the central object, it is not a thermal radiator like a star, but a source of non-thermal radiation emitted by high-speed electrons moving through intense magnetic fields. This fact, plus the strong gravitational field evident from the motion of the ionized gas, implies that the central object is a massive collapsed object—probably a black hole with a mass millions of times greater than our sun's.

Accretion of interstellar matter by a

central black hole may be the energy source of the violent phenomena seen in quasars and the nuclei of some galaxies. The VLA observations of our galactic center, made by Kwok-Yung Lo and Mark Claussen at the California Institute of Technology, mark the first time that the infall of gas has been directly seen in any galactic core or about any black hole.

Another new feature discovered with the VLA is an enormous arc of hot, ionized gas more than 140 light-years long, protruding from the galactic center. The streamer's narrow, filamentary structure is similar to that of solar prominences and reflects the influence of an extensive magnetic field. Although our galaxy is known to have a general magnetic field, this is the first indication that the field is akin to that of a simple bar magnet. Its cause may be similar to the dynamo mechanism proposed for the fields of stars and planets. The astronomers pursuing this inquiry were Mark

Morris at UCLA and Farhad Yusef-Zadeh and Donald Chance, both at Columbia University.

Understanding the precise nature of the galaxy's central object and any connection it may have with this magnetic field awaits an instrument of even higher resolution than the VLA, such as the Very Long Baseline Array, discussed elsewhere in this section.

Venus Volcano?

Evidence for volcanism has been found on the earth, the moon, Mercury, Mars, and Jupiter's satellite Io. Now the cloud-covered planet Venus may be added to this list, thanks to a radar map of a mountainous region on Venus called Isthara Terra. The map is the work of four astronomers—Donald Campbell, John Harmon, and Alice Hine at the National Astronomy and Ionosphere Center (NAIC) and James Head at Brown Uni-



Cosmic drain. A falling whirlpool of ionized gas, shown in this radio map, implies the presence of a massive black hole at the center of our galaxy.

versity. They used the 305-meter telescope of NAIC's Arecibo Observatory in work supported by both NSF and the National Aeronautics and Space Administration.

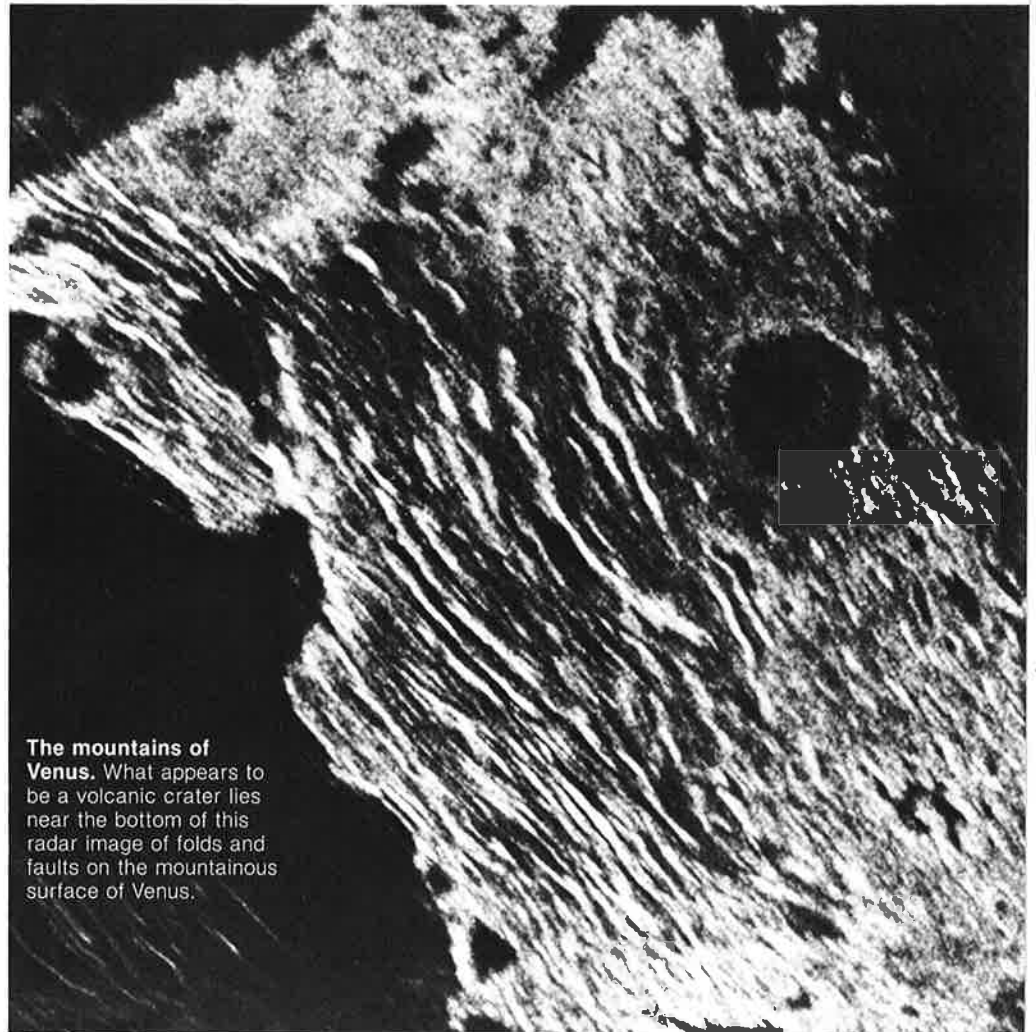
The map, made at a wavelength of 12.6 centimeters, has a resolution of three kilometers. Earlier, lower-resolution observations had revealed highlands but could not distinguish such narrow features as individual ranges. This map displays more than a dozen parallel mountain ranges, some quite steep and all resembling terrestrial folds and faults. One circular feature appears to be a volcanic crater.

Venus is of extreme interest in understanding the geology and evolution of the planets because it is approximately the same size and density as the earth and is earth's closest planetary neighbor. The question of the presence of plate tectonics and volcanism on Venus has been a subject of intense debate ever since the planet was first mapped at low resolution by the *Pioneer Venus* mission in 1978.

National Astronomy Centers

The National Astronomy and Ionosphere Center (NAIC), operated by Cornell University under contract with NSF, supports research programs in radio astronomy, planetary radar astronomy, and atmospheric science. Its main instrument, located near Arecibo, Puerto Rico, is a 305-meter antenna, the world's largest radio/radar telescope. NAIC also operates two remote sites north of the observatory: a 31-meter antenna used for interferometry, and the High-Frequency Ionosphere Heating Facility. Associated with the Arecibo telescope is a broad spectrum of observing and data processing equipment that includes receivers, very powerful radar transmitters, and computers.

Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, and the National Solar Observatory were consolidated into the *National Optical Astronomy Observatories (NOAO)* in FY 1984. NOAO is operated by the Association of Universities for Research in As-



The mountains of Venus. What appears to be a volcanic crater lies near the bottom of this radar image of folds and faults on the mountainous surface of Venus.

tronomy, a nonprofit consortium of 17 U.S. universities.

Kitt Peak National Observatory (KPNO), near Tucson, Arizona, is the nation's main center for optical and infrared astronomy research. KPNO gives U.S. astronomers access to the large telescopes, auxiliary instrumentation, and support services needed for observational and theoretical research in extragalactic, galactic, stellar, and planetary astronomy. Besides operating nine telescopes, KPNO offers sites and services on Kitt Peak for seven more telescopes operated by other institutions. Its four-meter Mayall reflector is especially well equipped.

The seven optical and infrared telescopes of Cerro Tololo Inter-American Observatory (CTIO) are the only ones

generally available to U.S. scientists for studying the southern skies. They include a four-meter reflector, the largest in the Southern Hemisphere and a near twin to the KPNO Mayall telescope. CTIO headquarters is in the coastal town of La Sereña, Chile, 80 kilometers from the telescopes in the mountains. The latitude of 30 degrees south and the exceptionally good atmospheric conditions are ideal for the study of such important Southern Hemisphere objects as the Magellanic clouds and the central regions of our own galaxy.

The National Solar Observatory (NSO) is the world's premier facility of its kind. Its Sacramento Peak site, at an elevation of 2,760 meters in New Mexico's Lincoln National Forest, enjoys unusually good observing conditions. The

Vacuum Tower telescope on Sacramento Peak produces very high resolution solar images, revealing the finest solar-atmosphere details observable from the ground. An impressive array of auxiliary instruments allows extremely accurate measurements of velocity and magnetic fields in the sun's atmosphere.

NSO's McMath Solar Telescope on Kitt Peak is the largest such telescope in the world. Its capabilities include spectroscopic studies of the sun at maximum wavelength resolution. Recent improvements have extended the high-resolution spectroscopic capability to stars other than the sun. Now in place is a research program on solar-type phenomena in other stars.

NOAO programs in detector development, optical coatings, and diffraction gratings benefit the entire astronomical community. NOAO has extensive engineering and technical facilities for designing and fabricating telescopes and instrumentation, and it participates in programs to develop new telescope technologies. For example, one instrument with an aperture of about 15 meters is expected to be the principal ground-based project for U.S. optical and infrared astronomy research in the next decade.

The National Radio Astronomy Observatory (NRAO) is one of the world's main centers for radio astronomy. Operated by the consortium of Associated Universities, Inc., NRAO has telescopes at three sites; its headquarters and data processing center are in Charlottesville, Virginia. Two single-dish (91-meter and 43-meter) telescopes at Green Bank, West Virginia are heavily booked by observers, whose interest in them has risen since the implementation of more sensitive receivers. Observations can be made at practically any wavelength from a centimeter to a meter. The 43-meter instrument is often used in conjunction with radio telescopes at distant locations in applying the technique of very long baseline interferometry.

On Kitt Peak, a second NRAO site, observations to wavelengths as short as 1 millimeter are now possible with the re-

surfaced 12-meter telescope. Finally, the Very Large Array (VLA) near Socorro, New Mexico offers a unique combination of high sensitivity and resolution for radio astronomy observations. Its 27 antennas are routinely used in different location patterns and at four standard frequency bands for continuum and spectral-line observations.

NRAO has begun technical design of the Very Long Baseline Array, a system of 10 antennas located between Hawaii and Puerto Rico and operated as a single instrument. The Array will dramatically improve resolution and sensitivity over the capabilities of any existing radio telescope, opening new areas of research in astronomy.

Atmospheric Sciences

The physical bases of climate and weather, the natural global cycles of gases and particulates in the earth's atmosphere, the composition and dynamics of upper-atmospheric systems—these are the study areas that concern atmospheric scientists. They strive to learn more about how the sun and neighboring planets relate to the earth's upper atmosphere and space environment. The Foundation supports research in these areas, mainly in universities, through seven grant programs, the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, and the Upper Atmospheric Research Program. NSF continues to be the chief supporter of academic research in the atmospheric sciences.

NCAR is operated by the University Corporation for Atmospheric Research, a nonprofit consortium of 54 North American institutions with graduate programs in atmospheric sciences, under a contract with NSF. Two main goals at NCAR:

- To plan and conduct research programs in cooperation with the atmospheric sciences community.
- To develop, maintain, operate, and make available services and facilities for atmospheric research, both in the universities and at NCAR.

NCAR staffers do research in atmospheric and ocean sciences and in solar astronomy. They also collaborate with

many institutions in large research programs. NCAR facilities serve all atmospheric researchers and part of the physical oceanography community. Those facilities include a computing center equipped with large mainframes, research aircraft, and ground-based Doppler radars. NCAR improves or develops instruments to measure atmospheric and oceanic parameters, including advanced weather radars, upper-air observing systems, buoys for ocean observations, and remote automatic weather-observing stations that report regularly to a central data collection point.

NCAR also offers fellowships for visiting scientists to work with NCAR staff.

NSF's Upper Atmospheric Facilities Program (UAF) supports operations and research at four large radar sites: the *Sondrestrom Radar Facility* in Sondre Stromfjord, Greenland; *Millstone Hill* near Boston, Massachusetts; *Arecibo Observatory* in Arecibo, Puerto Rico; and *Jicamarca Radio Observatory* on the magnetic equator in Jicamarca, Peru. Because there is a need for more information on global-scale thermospheric and ionospheric problems, these research facilities have been upgraded and are aligned in a longitudinal chain extending from the polar cap to the magnetic equator.

The UAF program also supports the High Frequency Heating Facility at Arecibo Observatory and a database at NCAR. The latter receives data from the

four UAF radars and makes that information available to the university community.

Atmospheric Response to Eclipse and Eruption

During the past decade, scientific understanding of stratospheric photochemistry has improved dramatically. Increased study has been prompted by the concern that human activities (aircraft flights, agriculture, use of synthetic chemicals such as chlorofluorocarbons) may perturb the ozone chemistry of the stratosphere, thereby increasing ultraviolet radiation at the earth's surface and causing undesirable climate changes and health hazards. This decade of research has produced important new insights and information about the chemical and dynamical processes that affect or control the chemical composition of the stratosphere. But despite these advances many questions remain.

One line of inquiry for the past several years is that of NSF grantee Clyde R. Burnett of Florida Atlantic University, working with Elizabeth Beaver Burnett of the National Oceanic and Atmospheric Administration's Aeronomy Laboratory in Boulder, Colorado. They have been systematically measuring and evaluating

the column abundance of the hydroxyl radical (OH), a key species in the stratospheric photochemical system. The Burnetts' data, which come from high-resolution spectroscopic measurements of sunlight absorption, have been instrumental in testing the models that scientists use to describe the photochemistry of the stratosphere.

During the partial solar eclipse that occurred 30 May 1984, this research team made OH measurements at Fritz Peak Observatory near Boulder. The eclipse apparently triggered an oscillation in the OH concentration (and, by implication, in much of the photochemical system) of the middle atmosphere. The maximum reduction in

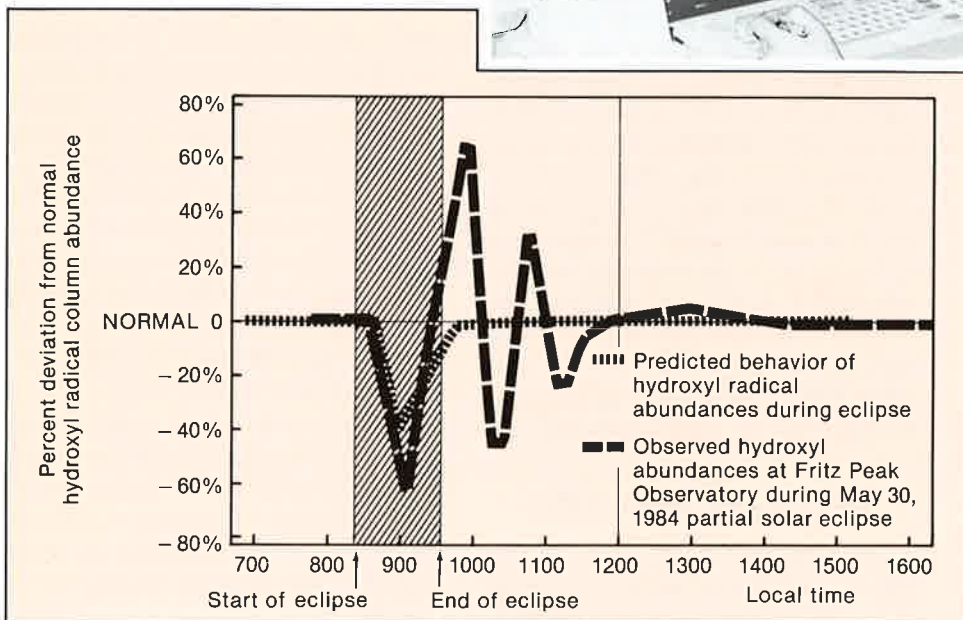
solar flux was 37 percent at 9:00 a.m. local time; the corresponding OH abundance was reduced by half of its normal baseline value. The OH abundance recovered rapidly and, during the final 30 minutes of the two-hour eclipse, exceeded the normal value by about 40 percent. It then oscillated for another two hours, approaching normal values at midday.

This was the first observation of a "ringing" response to a solar eclipse by a photochemically produced atmospheric constituent; current models of stratospheric chemistry predict a return to normal and steady-state values within minutes of any change in solar intensity.

Since 1976, the ground-based measurements of OH from Fritz Peak Obser-



First observers of response to eclipse. Clyde R. and Elizabeth Beaver Burnett, in measuring an atmospheric constituent (hydroxyl) during a solar eclipse, first observed a "ringing" response that advances understanding of the stratosphere's chemical composition.



Eclipse response. The observed hydroxyl (OH) abundance at Fritz Peak Observatory during the May 30, 1984 partial solar eclipse exceeded the expected and normal steady-state values during the final 30 minutes of the eclipse by about 40 percent. Fluctuations in the OH column abundance then continued for an additional two hours.

vatory have shown significant diurnal, seasonal, and solar-cycle variations. When part of the aerosol cloud from the El Chichon volcano passed over the Colorado observatory site in the summer of 1982, OH abundance rose temporarily. Distinct geographic differences also have been found in OH measurements taken at Boca Raton, Florida and at Fairbanks, Alaska.

Although the general level of OH abundance and its diurnal behavior are in fair agreement with current atmospheric models, these findings suggest that there are still uncertainties about chemical and/or dynamical processes in the stratosphere.

Modeling the Ice-Age Climate

Climate modelers have long wondered about the nature of atmospheric circulation during the last ice age (15,000 to 20,000 years ago). In the past decade there has been considerable progress in understanding what happened when an ice sheet 2,500 meters thick covered a large part of North America, and North Atlantic sea ice extended south to the coast of Spain.

The Cooperative Holocene Mapping Project (COHMAP)—a multiinstitutional project at the University of Wisconsin (John E. Kutzbach), University of Minnesota (Herbert Wright) and Brown University (Thompson Webb)—has attacked this problem on two fronts. First, the scientists capitalized on the many improvements in NCAR's Community Climate Model, which they adapted to ice-age boundary conditions. Second, they reconstructed evidence from land-pollen records and used it to evaluate regional climate patterns simulated by the model. The database from the land record augments a similar one already produced in the 1970s for the oceans through yet another NSF-supported project—the Climate Mapping Project (CLIMAP).

Recent model results indicate that the ice sheet and sea ice greatly affected atmospheric circulation. The ice sheet was

large enough to act as a mountain barrier to upper-level winds (the jet stream). The upper westerlies split around the huge ice dome, with one branch flowing north and the other south. The convergence of these flows over the central North Atlantic produced extremely strong winds that extended east into Europe.

A comparison of simulated climate with the COHMAP database has shown some remarkable correspondences. Given the anomalous upper-air configurations, the model simulated realistic changes in temperature and precipitation. High lake levels in the U.S. Southwest, evidence of arctic tundra on the Great Plains, and relatively mild summers in the Northeast are all consistent with the model's simulations.

Similar agreements between model and data can be found for the central North Atlantic, western Europe, North Africa, and the Middle East. In the Atlantic, surface winds were so strong that the velocity of the Gulf Stream apparently speeded up. The increased transport of warm waters from the tropics resulted in a local rise in sea-surface temperatures, even as the ice sheet was moving south.

This agreement between model and data has implications for another important climate problem—the carbon dioxide (CO₂) "greenhouse" effect. Although all climate models indicate that temperatures will get warmer, the models disagree as to whether particular regions will be wetter or drier. In the past, there was no way to evaluate different model simulations to decide which might be correct. The COHMAP group has shown that it is now possible to produce and verify regional climate simulations. Future models will be tested against the COHMAP database; their results can be used to evaluate carbon-dioxide scenarios. Climate modelers are looking forward to this next stage of development.

The Fourier Tachometer

Like a ringing bell, the sun is oscillating—expanding and contracting in many ways—and we can learn much about the

sun by studying those oscillations. Timothy Brown of NCAR's High Altitude Observatory, working with John Evans of the NSF-supported National Solar Observatory, has developed a new instrument, the Fourier tachometer, to measure these vibrations on the sun's surface (the photosphere).

Solar oscillations are far too small to be observed visually, but they cause Doppler shifts in the wavelengths of light that scientists can measure. Analysis of these shifts can yield information not only on the sun's various modes of oscillation but also on its magnetic fields and the dynamics of the solar convection zone.

Measurement of the Doppler shifts requires a high-precision instrument. It should be able to measure rapidly changing shifts (involving velocities no greater than 30 centimeters per second) on time scales of minutes, as well as slowly changing shifts (produced by velocities of roughly 20 meters per second) on time scales of hours to days. Not only has the Fourier tachometer met all these requirements but it has spatial resolution, allowing scientists to look at either the whole visible solar surface or just a portion of it.

The tachometer has two interacting parts, an optical system and a detector with associated electronics and control system. The optical system, built by the National Solar Observatory, produces an image of the sun which is continually modulated in intensity, making the image flicker. Scientists extract information about the Doppler shifts from the variation between brighter and dimmer intensities. The electronics system, designed and built by the Instrumentation Group of the High Altitude Observatory, measures the intensity of the solar image, converts it to a digital signal, then creates a diagram of the Doppler shifts of solar radiation—called a velocity map.

This instrument is used to study the so-called five-minute oscillations. They consist of millions of independent, small-amplitude oscillations of different spatial scales. Their combined effect makes the sun seem to be "beating" every five minutes in a complex spatial pattern.

Earth Sciences

Earth scientists are now applying plate-tectonic concepts to the ancient (3 to 4 billion years) and geologically complex continents. These concepts, developed largely from studies of the geologically young (less than 200 million years) and relatively simple ocean basins, are being tested rigorously. Discoveries about how continents are assembled and how they deform have important implications for developing resources and for understanding geologic hazards such as earthquakes and volcanic eruptions.

Earth science research supported by NSF is at the forefront of these developments, seeking more understanding of the earth's processes and its evolution through time. To encourage new directions in such research, NSF established two new programs in 1984:

- The *Instrumentation and Facilities Program* will help research laboratories buy or build modern analytical equipment. Many first-class researchers are operating with tools that by modern standards are imprecise, inefficient, unreliable, or simply worn out. Replacing these tools can be very expensive; this program will provide some much-needed financial aid.
- The *Continental Lithosphere Program* will support a few large, potentially expensive research efforts to unravel the complexities of the continents.

Descriptions of research achievements from last year follow.

Are Diamonds Really Forever?

The age and origin of diamonds have remained obscure despite decades of study. Diamonds can be formed only at such high pressure and temperature (50 kilobars or 725,000 pounds per square inch at 1,400 degrees centigrade) that they must crystallize at depths in excess

of 100 miles or 160 kilometers within the earth. Few other materials come unchanged from such great depth.

Diamonds, which consist entirely of carbon, are so chemically pure that they carry little or no geochemical information about the deep part of the earth. However, about one diamond in a thousand contains a minute mineral inclusion. Some of these inclusions can be used for geochemical studies; they are protected from outside chemical alterations by the impervious nature of the diamond host that brings them to the surface. The inclusions are so small (three million weigh only one ounce) that an isotopic age determination of a single one is not yet technologically feasible.

MIT geochemist Stephen Richardson and three international coworkers, with help from DeBeers Consolidated Mines, sorted 1,200 diamonds from a production line of stones out of the company's Finsch and Kimberley mines in South Africa. Each diamond—containing one or, rarely, two garnet inclusions—was cleaved by hand; the inclusions were then removed and aggregated in two batches of 600 each. Working in the laboratory of Stanley Hart at MIT, Richardson then made an age determination of each batch, based on the radioactive decay of an isotope ($^{145}\text{Samarium}$ to $^{143}\text{Neodymium}$) that can be measured in very small quantities on a modern mass spectrometer. Even using hundreds of inclusions, this procedure represented the limit of what can be measured with state-of-the-art technology.

Analyses of the two batches of garnet inclusions were in perfect agreement.



Gem within a gem. The rare occurrence of garnet crystal inclusions in diamonds establishes the age of the diamonds at more than 3 billion years. This suggests that the earth's present crustal plates existed at an early stage of the planet's history. The garnet crystal seen here is about 150 microns (0.006 inches) across.

They established unequivocally that the age of these diamonds is 3.3 billion years. The diamonds, brought to the surface only 100 million years ago, had remained unchanged deep within the earth for about three-quarters of the earth's age span.

These findings have profound implications for ideas about the early evolution of the earth. It appears that the relatively thick, rigid plates that form the present-day crust have existed from very early in the earth's history. (Those plates are 50 to 150 miles, or 80 to 240 km, thick; their motion triggers most of the geologic processes we observe—mountain building, earthquakes, volcanic eruptions.) Diamond-bearing volcanic materials are found only in thick plates; if the plates had not existed when the diamonds formed, we would expect to find diamonds in other areas as well. It seems that the dominant geological processes of the present were operating in like fashion when the earth was young.

Origins, Sutures, and Geologic Time

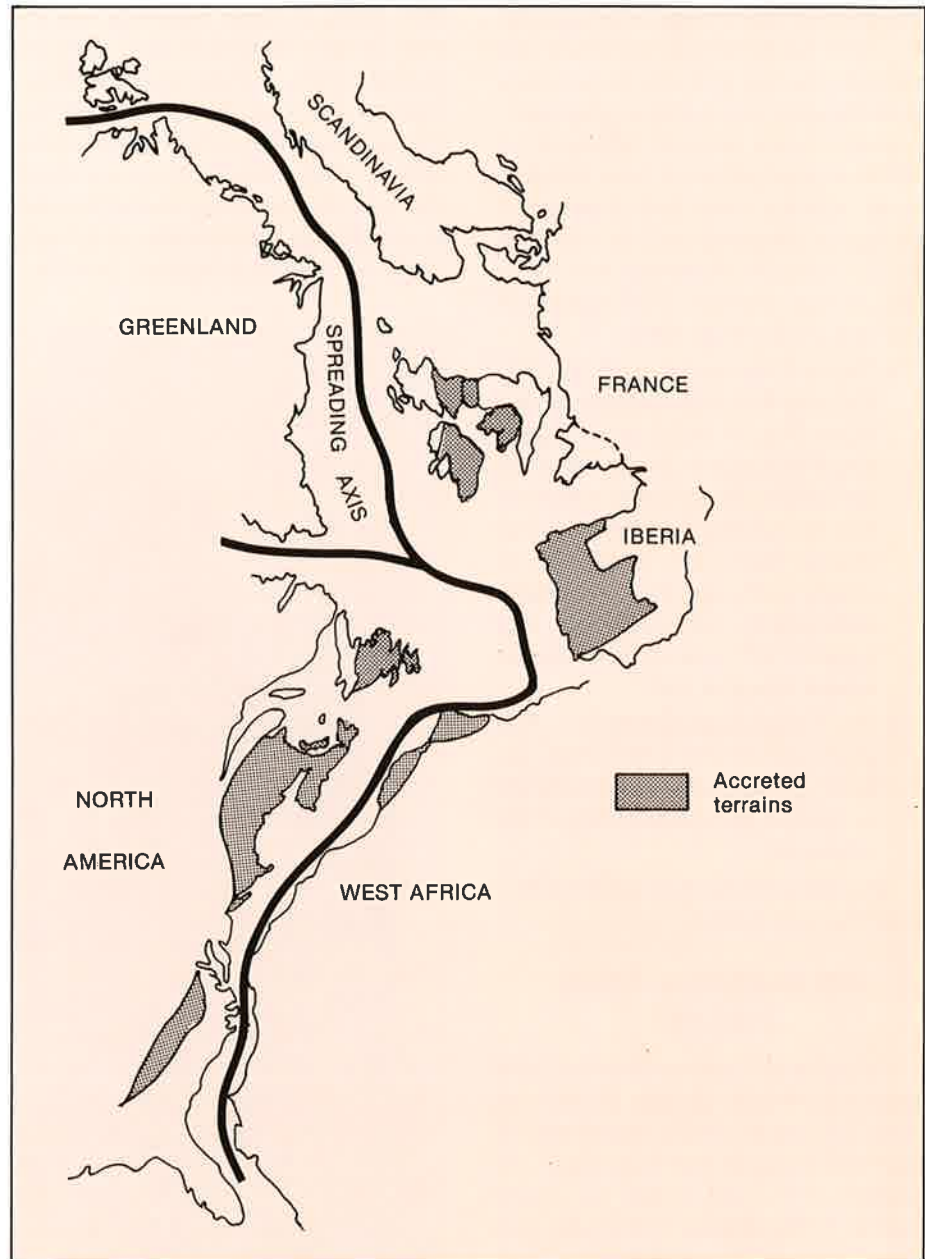
Central to the idea of plate tectonics is the fact that, over time, continents accrete new land masses at their margins. This process has been verified by identifying a number of terrains that apparently traveled far before lodging in western North America. Several researchers, including Robert Coe at the University of California, Santa Cruz, and Darrel Cowan at the University of Washington, have shown that at least for the past 100 million years, the Pacific plate has been side-swiping the North American block. Nearly intact masses have slid onto the continent; although banged and dented, these once-migrant terrains display both paleontological and paleomagnetic evidence that they formed at latitudes and times far different from the rocks with which they collided. Definite contacts or sutures can be identified between the newcomers and the older parts of the North American crust.

Eastern North America, too, has accumulated terrains. However, instead of

sliding into the North American block along linear transform faults, the rocks that arrived from the east seem to have had a series of head-on collisions; the Appalachians are one result. Crustal subduction and volcanism heat the incoming terrain material so that much of the new rock is greatly changed and recrystallized, removing the paleomagnetic signature of latitude formation and erasing any fossil record it might have

contained. Even so, careful field work and laboratory analyses have allowed several workers, including Robert Hatcher and Donald Secor at the University of South Carolina, to identify three collisions in the geologic past. The evidence for the first two is almost completely obliterated but the most recent, the Alleghenian (260 million years ago), has left mountains that still dominate the eastern topography. However, those

Ancient North Atlantic. Some 65 million years ago Europe, Africa, and North America were connected. Shaded areas show accreted terrains welded to older continental masses.



mountains are but feeble reminders of the more-than-alpine stature they must have had when arriving terrains crashed into the North American block.

Because the terrains collided, the rock deformations they produced show extensive thrust faulting, with the new material moving up to override older material. Paleomagnetic studies by Rob Van der Voo at the University of Michigan suggest that these faults mark the collision and welding together of the North American block with the mega-continent Laurentia (today's Eurasian block) and Gondwanaland (now South America, Africa, Australia, India, and Antarctica).

The great suture that should mark the seam of this vast weld has yet to be clearly identified. Perhaps, considering the complexity of these tectonic events, the suture differs from those found in western North America. Much more work is needed before these relationships will become clear.

Seismic Tomography

One of the more dramatic breakthroughs in our study of the earth has been application of the seismic tomography technique to an understanding of the earth's deep interior. In medical tomography, x-rays are passed through human tissue along many paths; a computer program makes it possible to analyze the degree of absorption encountered by any single ray and to integrate these analyses into a three-dimensional picture of the organs involved in the absorption. Research groups at Caltech and Harvard realized that this approach could be applied to the earth too, using seismic waves instead of x-rays. Thus, surface waves from large earthquakes that orbit the earth many times can be used to make a global map of velocity variations in the upper mantle. Fortunately, different wavelengths sample to different depths, so a three-dimensional picture of material causing seismic anomalies is possible. Shear waves, also produced by earthquakes, are used to sample deeper levels of more than 250 miles, or 400 km, beneath the surface.

Seismic tomography is in its infancy; to take full advantage of its potential the network of seismometers must be greatly expanded. Nevertheless, scientists have already made some significant observations. First, there is evidence that the earth's mantle—the thick shell of 1,800 miles or 2,900 km beneath the crust and above the core—is quite heterogeneous, at least in its upper part. These mantle heterogeneities correlate well with major surface features.

Higher seismic velocities presumably occur in rock material that is cooler, and therefore denser, than its surroundings; regions with lower seismic velocities represent hotter, less dense material. Large masses of apparently hot material are under the East Pacific Rise, western North America, and the Red Sea region of Saudi Arabia and East Africa—areas that are believed to be pulling apart. Faster velocities representing colder material are found in island arc areas—collision

zones where one plate of cold crustal material is forced down into the warmer upper mantle beneath another plate.

Such results are not unexpected, but similar fast-velocity (cooler) zones are also found beneath the western Atlantic and much of South America. Donald Anderson at Caltech has suggested that these cold spots in the upper mantle result from crustal material of the Pacific plates that has been overridden for great distances by the lighter and thicker American plates. That view contrasts with earlier indications that this dense Pacific crust may have been subducted deep into the mantle, perhaps all the way to the core, where it would be reheated and rise again.

Clearly, more evidence is needed from a variety of sources, and seismic tomography promises major contributions to our understanding of vast parts of the earth beyond the reach of direct observation.

Ocean Sciences

The ocean sciences depend heavily on equipment. General-purpose vessels continue to be the backbone of this research, but they are now supplemented by satellites, remote underwater vehicles, manned submersibles, drillships, instrumented buoys, powerful computers, and aircraft. Oceanography also involves many scientific fields—chemistry, biology, geology, and geophysics, to name a few.

Another feature of modern oceanography is its international nature. Many research problems are so large and complex that scientists from several countries must work together to solve them. The Ocean Drilling Program, for example, is an international effort supported by 6 scientific organizations and 12 countries. Large-scale, long-term activities, such as climate studies, are aided by multi-lateral organizations. These include the

Intergovernmental Oceanographic Commission and the International Council of Scientific Unions.

In 1984, NSF continued to support about 70 percent of the operations in the federally funded academic research fleet. The research vessel *Atlantis II* began service as tender for the deep-submersible *Alvin*, thereby improving the effectiveness of exploration on the deep-sea floor.

Ocean Drilling

Fiscal year 1984 was a time of transition for this program. The drillship *Glomar Challenger* was retired after 15 years of operation with the Deep Sea Drilling Project, which had an extraordinary record of scientific productivity and technical accomplishment:

- It produced evidence confirming

and quantifying the concepts of plate tectonics.

- It furnished the tools and insights needed to launch the new discipline of paleo-oceanography.
- It also made major contributions to studies of global climate and ocean circulation, drilling technology, earthquake prediction, biologic evolution, and the origins of metals.

These achievements led to a new program of scientific ocean drilling, beginning in January 1985. The new effort is supported jointly by NSF and by several foreign countries. It will involve a modern drillship with greatly enhanced capabilities—the *JOIDES Resolution (SEDCO/BP 471)*. During 1984, new laboratories were installed on the ship, and its drill rig was upgraded to handle a scientific coring apparatus and other equipment.

A consortium of 10 major U.S. facilities, the Joint Oceanographic Institutions, manages and operates the new activity. Planning is handled by the Joint Oceanography Institutions for Deep Earth Sampling (JOIDES). This organization represents the international scientific community: the European Science Foundation, Canada, France, Germany, Japan, the United Kingdom, and the United States.

The program's first expedition, or leg, is studying the evolution of the Bahamas carbonate platform. The world's great accumulations of hydrocarbons are associated with structures such as this one. Drilling in the Bahamas will help to decipher the origins of carbonate platforms and may point the way to other areas of resource exploration.

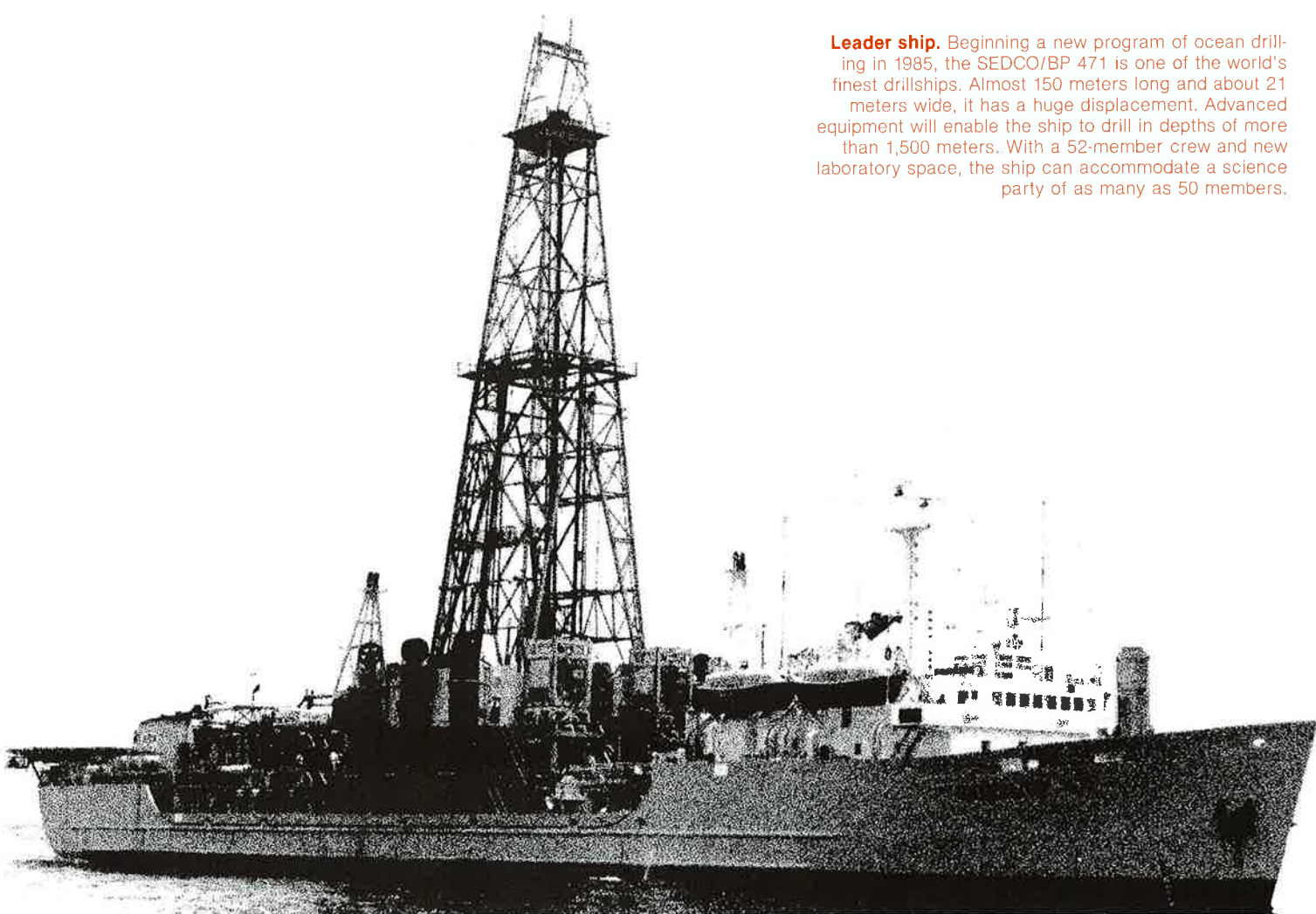
In the second leg, the focus will be on geophysical experiments and measure-

ments in drill holes, using new downhole instruments. The increased stability and other features of the new *SEDCO* vessel will allow many downhole experiments that were not possible with *Glomar Challenger*.

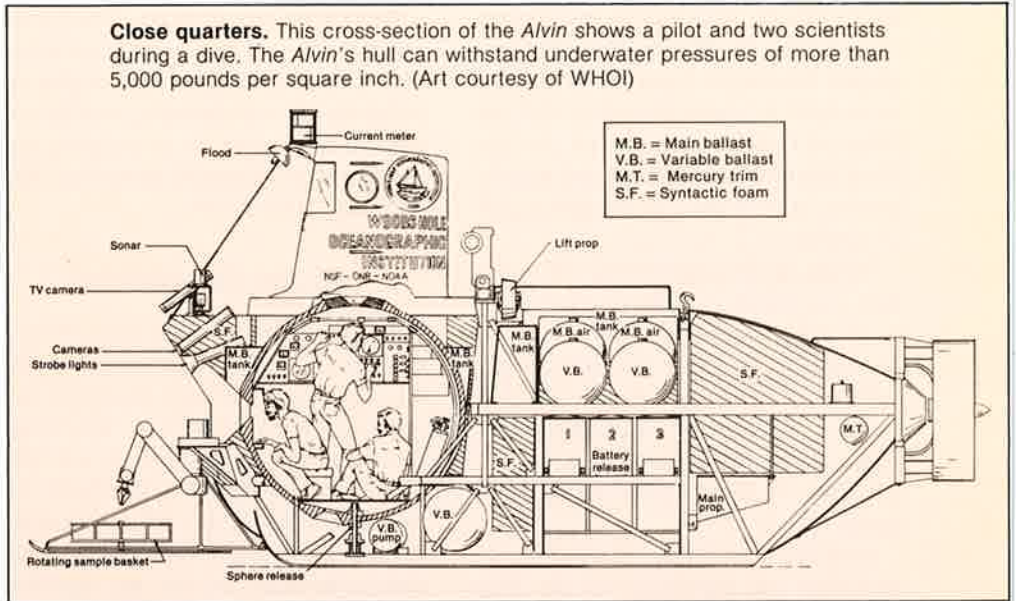
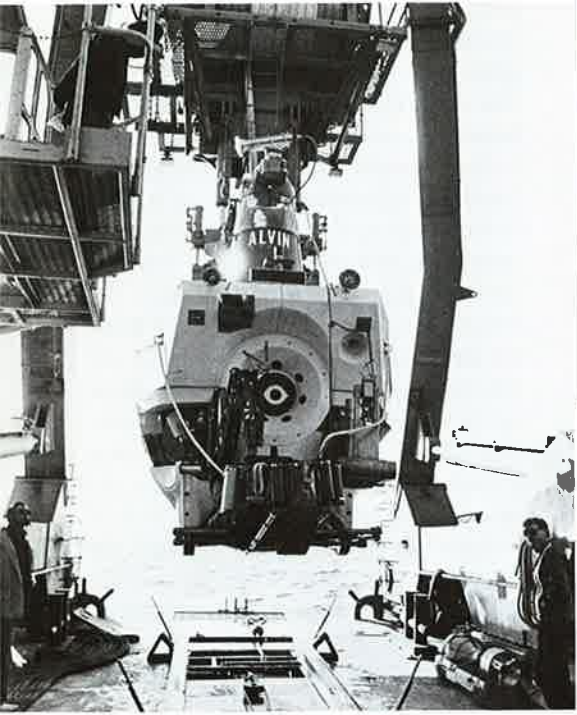
In the eastern North Atlantic, slow sediment accumulation allows drilling teams to sample deep structures on the continental margins. In the third and fourth legs, there will be drills in such structures on the Galicia Banks off northwestern Spain and on the Voring Plateau in the Norwegian Sea. The new vessel's ability to penetrate more than 1,500 meters makes such studies possible.

The new ship also is ice strengthened, permitting work under the challenging ice conditions of the Labrador Sea. The objective there will be to study the history of oceanic circulation and associated changes in global climate.

Leader ship. Beginning a new program of ocean drilling in 1985, the *SEDCO/BP 471* is one of the world's finest drillships. Almost 150 meters long and about 21 meters wide, it has a huge displacement. Advanced equipment will enable the ship to drill in depths of more than 1,500 meters. With a 52-member crew and new laboratory space, the ship can accommodate a science party of as many as 50 members.



At home in the deep. The 20-year-old submersible *Alvin*, here shown being lifted from the deck of the *Atlantis II* before launching, has enabled ocean scientists to spend more than 8,000 hours studying the ocean floor. (Photo by Rod Catanach, Woods Hole Oceanographic Institution [WHOI], Woods Hole, MA).



Into the water. The *Alvin*, beginning one of almost 1,400 dives, is lowered into the ocean from the stern of *Atlantis II*. (Photo by Larry Workman, WHOI)

The first year will be capped by an attempt to drill in areas with little or no sediment cover—a feat never before accomplished. Bare-rock drilling will let oceanographers study petrologic and geochemical features of the midocean ridges. The strategy is to drill a cluster of shallow holes to study the upper crust, and a single deeper hole to examine processes below. This hole will also allow

reentry for long-term instrumentation, creating a semipermanent observing capability.

Update on *Alvin*

In fiscal year 1984, 167 NSF oceanographic projects took place on ships of the academic research fleet, also known as UNOLS (University-National

Oceanographic Laboratory System). The projects required nearly 3,650 days at sea, involved 38,000 “scientist days” (also includes work by graduate students and technicians), and ranged from the Arctic Ocean to the Southern Ocean and from the western Pacific to the South Atlantic.

The year 1984 marked the 20th anniversary since the Deep Submergence Re-

search Vehicle *Alvin* was commissioned. Operated by the Woods Hole Oceanographic Institution (based in Massachusetts), *Alvin* is jointly funded by NSF, the Office of Naval Research, and the National Oceanic and Atmospheric Administration, part of the U.S. Department of Commerce.

During its 20-year history, *Alvin* has been the workhorse for manned deep-ocean investigations. At this writing, it has made 1,391 dives and spent about 8,100 hours submerged. Built and owned by the U.S. Navy, *Alvin* can operate at depths of nearly 4,000 meters, where pressures exceed 5,000 pounds per square inch.

Alvin has been greatly instrumental in advancing our knowledge of the deep seas. In 1977 its divers found vents of warm water (60 degrees Fahrenheit) in the ocean floor near the Galapagos Islands. Hot-water vents (715 degrees) have since been discovered farther north in the Pacific Ocean. More interesting than the vents themselves was the unexpected discovery of animal life existing around them, in an environment totally devoid of sunlight. Small fish and crabs exist in abundance, along with tube worms measuring 2.5 meters (8 feet) and clams stretching to more than 25 centimeters (10 inches). These life forms feed on organic matter produced by bacteria using a sulfur-based system instead of photosynthesis.

The new handling system on the *Atlantis II* has sharply decreased the time needed to launch and recover *Alvin* and has increased the submersible's ability to operate in rough seas. The size (64 meters), range (19,300 kilometers), endurance (38 days), speed (13 knots), and accommodations (for 24 scientists) of the

Atlantis II far exceed those of the former tender *Lulu*, and they greatly extend *Alvin*'s global capabilities. Far-ranging expeditions are now possible, and the new capability to operate in rougher seas means about 50 percent more dives than the *Lulu* could handle.

Ocean Circulation

VERTEX (Vertical Transport and Exchange) is a step toward understanding the interactions between biological and physical processes and how they affect the chemical composition of seawater. This research program in the Pacific has been investigating the vertical transport of materials in association with passively sinking particles and the way dissolved substances exchange with these particles. Cooperating scientists have come from several universities and other institutions (see list elsewhere in this section).

These researchers have been studying phytoplankton (single-cell plants), zooplankton (small animal life), and decomposers (microorganisms) in relation to their physical and chemical environments. Transport studies have been coupled with flux measurements made with particle traps set throughout the upper 2,000 meters of the water column. Elements and compounds that the scientists have measured in seawater and in the trapped particles include carbon, nitrogen, phosphorus, trace elements, and organic compounds.

These combined biological, chemical, and physical studies have yielded insights into (1) the removal of inorganic and organic pollutants from the sea surface, (2) nutritional aspects of the mid-water column, and (3) the basic bio-

geochemistry of the sea's upper layers.

VERTEX has shown that the distribution of substances within the water column depends on the ocean's horizontal—rather than vertical—transport processes. Elements being removed via particles cannot be resupplied by vertical mixing processes from above or below a given water layer. Hence the conclusion that materials are resupplied through horizontal mixing.

For example, dissolved manganese levels are higher near shores than in open ocean waters because continental weathering processes introduce this element into the coastal ocean. Its levels are lower offshore because the waters there are farther from the source of supply, and also because manganese is rapidly taken up by sinking particles in middepth waters. Using inshore-offshore data on dissolved manganese, together with removal rates for the element, scientists estimate that it takes 10 to 20 years for manganese to travel from continental areas such as California to open-ocean regions such as those north of Hawaii.

The VERTEX study of manganese and other elements and compounds—along with similar research in other NSF-sponsored programs—will eventually lead to an understanding of the effects of deep-ocean circulation on ocean chemistry. Basic knowledge about that circulation has important implications. For example, the United States may have to mine the seas for strategic elements that are in limited domestic supply. One of these, cobalt, seems to be tied somehow to manganese, as the Hawaii VERTEX studies suggest. (Horizontal transport and sinking-particle processes may be forming the cobalt-rich manganese crusts found near Hawaii.)

Although much information can come from limited studies like VERTEX, true understanding of oceanic processes will require similar research efforts on a much bigger scale.

Sea Productivity

Upwelling areas in the ocean are those where water from below, which may be

Home Institutions of VERTEX Scientists

Bodega Marine Laboratory, Bodega Bay, California
 University of California, Santa Cruz
 University of Hawaii, Manoa
 International Laboratory of Marine Radioactivity, Monaco
 Moss Landing Marine Laboratories, Moss Landing, California
 Oregon State University, Corvallis
 Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

rich in nutrients and different in temperature, rises to the surface. These upwellings can greatly affect the sea's production of fish, plants, and other life forms.

Richard Dugdale at the University of Southern California, Ken Brink at the Woods Hole Oceanographic Institution, David Stuart at Florida State University, and others have studied a Pacific upwelling area closely. They used shipboard observations as well as satellite and aircraft remote sensing to obtain, for the first time, an integrated, three-dimensional picture of the physics and biology of such an upwelling area. For example:

- They found that upwelling of nutrient-rich water is strongest near capes and promontories.
- They also documented the daily to weekly variability of production in response to changes in wind stress.
- They noted that pulses in upwelling lead to patchy and variable distributions of marine production, which probably affect the survival of fish larvae and the success of fisheries on the California coast.

Determining the amount and variability of marine production is critical in understanding biogeochemical cycles, determining carbon dioxide fluxes between the atmosphere and ocean, and predicting fish harvests. Then too, recent discoveries have caused us to question traditional thinking about the role of the environment, the biology of the sea, even the organisms responsible for ocean productivity. For example, past estimates of global ocean productivity—from 20 to

30 billion tons of carbon per year—may have underestimated the true value by two to five times. Secondly, phytoplankton were long thought to be the overwhelmingly predominant ocean producers. It now appears that photosynthetic and chemosynthetic bacteria are also important.

Two forms of bacteria reported by Stanley Watson and John Waterbury, from the Woods Hole Oceanographic Institution, may account for 10 to 20 percent of primary production in the open sea. Then too, the ubiquitous chemosynthetic bacteria can use energy sources other than sunlight and carbon to produce living matter. John Sieburth at the University of Rhode Island has isolated marine bacteria that use naturally occurring methane and formaldehyde as carbon sources. He hypothesizes that they are important, but previously overlooked, producers.

These discoveries have resulted in part from the application of new technologies, such as remote sensing in upwelling areas. Researchers also have come up with new methods, such as rapid acoustic and optical techniques, to determine plankton distributions. A prototype acoustic sampling system developed by Van Holliday of Tracor Corporation and Richard Pieper at the University of Southern California has provided rapid analysis of zooplankton distribution. Soon this and other new techniques will give us three-dimensional snapshots of marine food webs and the dynamic interactions of organisms that contribute to ocean productivity.

This program stresses interdisciplinary work. Rapid development and environmental fragility in the north point to the need for such research, and the arctic is a unique laboratory for looking into many basic scientific questions.

The Arctic Research Program supports roughly half of the arctic research funded by NSF. Other Foundation programs fund the rest through awards for projects in the various scientific disciplines.

Alaskan Enigma

The great productivity—notably among fishes, birds, and mammals—of high-latitude seas on the continental shelf presents an ecological enigma. Why do icy oceans with limited growing seasons yield consistently high returns of certain organisms? An expedition led by C.P. McRoy at the University of Alaska sought information on this puzzle from the shelf waters of the North Bering and Chukchi Seas.

The expedition was planned around a hypothesis that the driving forces for productivity in these waters are the nutrients and organic material supplied by North America's fifth-largest river—the Yukon. Instead of confirming the hypothesis, scientists on the cruise discovered that ocean currents and mixing processes over the continental shelf were the major causes, at least at that particular time.

The continental shelf of the Bering and Chukchi Seas adjacent to northwest Alaska is a broad plateau over which the water is rarely deeper than 50 meters. This plateau is larger than half the state of Alaska; waters flow across it from south to north through the Bering Strait. The flow is seasonal, being greater in summer, and it has three masses. In the west the flow is cold and highly saline water from the Gulf of Anadyr, which begins as a river in Soviet Russia. The middle component is the Bering shelfbreak current, warmer than water from the Anadyr but similar in other properties. In the east is Alaskan coastal water dominated by the discharge of the Yukon River. The

Arctic Research

The fields supported here are upper-atmospheric sciences, meteorology, glaciology, geology and geophysics, oceanography, and biology. Study areas have included:

- The Arctic Ocean, and the far north-

ern portions of the Atlantic and Pacific Oceans.

- Arctic and glaciated parts of Alaska, northern Canada, Greenland, and the islands administered by Norway and collectively called Svalbard.

Anadyr and Bering waters in the west, and the Alaskan coastal and Yukon waters in the east, all maintain their identities through the Bering Strait into the Chukchi Sea.

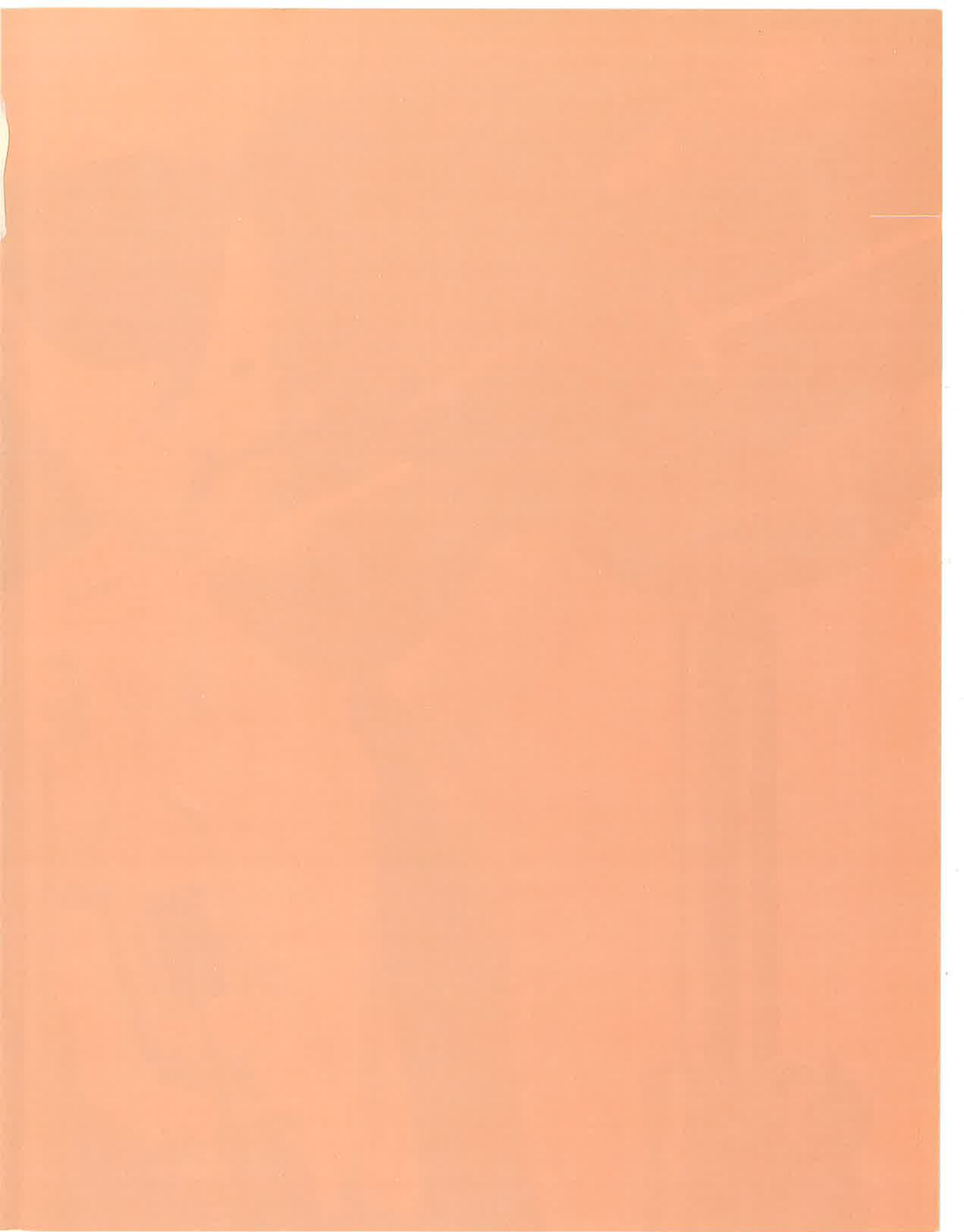
The Anadyr and Bering waters have high nutrient content; these nutrients are continuously supplied to the shallow waters of the northern Bering-Chukchi shelf, resulting in a large crop of phytoplankton. These populations do not grow year-round, however; in this region near the Arctic Circle, a lack of sun limits them in the winter. Moreover, ice usually is present until June, so the phytoplankton growth period probably is

confined to June through September.

Based on their expedition findings, McRoy and his colleagues have suggested that summer production on this shelf is analogous to the continuous culture of algae in a laboratory, where favorable growth conditions are maintained by continuous addition of nutrients and continuous removal of cell yield. During summer the measured productivities were 2 to 4 grams of carbon per square meter per day (the average for the world ocean is 0.1 gram per day). The scientists have conservatively estimated annual production at 324 grams

per square meter. This figure does not include production during autumn and at the bottom of the ocean. Still, their estimate is about twice the production measured in the southeastern Bering Sea, and it ranks the northern Bering-Chukchi region among the most productive of shelf seas.

The contribution of the Yukon River and the Alaskan coastal waters to production in the region remains a question. These waters may stimulate primary production for a short time just after the sea ice leaves, but more work will be needed to investigate this factor.





Biological, Behavioral, and Social Sciences



A striking feature of the research supported by NSF in these areas is diversity. Research reports in this chapter deal with subjects ranging from neurons to the Amazon River basin, from enzymes to the U.S. economy. Other research reported includes the history of lasers and investigations of such topics as ancient *Homo sapiens*, primitive crustaceans, hemoglobin, dehydration, and intellectual property.

Perhaps the most significant change in these programs during FY 1984 was the emergence of two new NSF divisions from one. The ten programs in the Physiology, Cellular and Molecular Biology Division were distributed among two new divisions, Molecular Biosciences (MB) and Cellular Biosciences (CB). The Genetics Program was divided into Prokaryotic Genetics in MB and Eukaryotic Genetics in CB. These changes reflect in part the growth in research on recombinant DNA and the importance of the biotechnology revolution.

At the end of FY 1984, the Biological, Behavioral, and Social Sciences (BBS) directorate had 6 divisions and 37 programs. During the year several new activities and emphases appeared, along with the organizational changes noted above. For example:

- *Grants for Research on Teaching and Learning in Science and Mathematics* was a congressionally mandated initiative responding to reports by public and private commissions. These reports had expressed serious concerns about the

adequacy of U.S. educational efforts in science and engineering. Twenty-six research awards for \$3 million were made by three BBS divisions in support of this initiative.

- *Postdoctoral Research Fellowships in Environmental Biology* were inaugurated during the year. Fellows are selected for their potential ability to aid the flow of innovative and imaginative research ideas in environmental biology by learning new and sophisticated research techniques.
- A new competition for *Archaeometric Projects* was announced by the Anthropology Program. Awards will support laboratories that provide archaeometric services; projects to develop and refine archaeometric techniques; and proposals to apply existing techniques to specific bodies of archaeological material.
- An NSF-sponsored *Workshop on "Chemistry of Life Processes"* resulted in a program announcement, distributed in September 1984, that called for collaborative research between chemists and biologists. This is expected to stimulate extensive cooperative work, a key focus at NSF.
- In a statement of June 1984, following an intensive study, the National

Table 2
Biological, Behavioral, and Social Sciences
Fiscal Years 1983 and 1984

(Dollars in Millions)

	Fiscal Year 1983		Fiscal Year 1984	
	Number of Awards	Amount	Number of Awards	Amount
Molecular Biosciences	1,491	\$ 87.34	863	\$ 53.95
Cellular Biosciences			750	47.13
Biotic Systems and Resources ...	716	45.96	749	52.77
Behavioral and Neural Sciences ..	694	34.02	728	38.09
Social and Economic Scis.	462	20.29	452	24.50
Info. Sci. & Tech.	65	5.48	86	6.15
Subtotal	3,428	\$193.09	3,628	\$222.59
Adjustment to Internat'l Awards	—	-1.86*	—	—
Total	3,428	\$191.23	3,628	\$222.59

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.
SOURCE: Fiscal Years 1985 and 1986 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) and NSF accounting records.

Science Board asked NSF's Director to develop and expand programs focusing on research and education in *Biotechnology*, an area of growing scientific importance.

- For the first year of the *Presidential Young Investigator Program*, 27 awards were made in four BBS divisions. This is a special effort to encourage young science and engineering faculty members in the early stages of their careers.
- BBS greatly increased its support of research to *Primarily Undergradu-*

ate Institutions. The more than \$11.5 million awarded during FY 1984 represented an increase of about 50 percent over the previous year. This reflected the Foundation's growing concern about those institutions. (See also the later section on "Research Initiation and Improvement," in chapter 6.)

The change and growth summarized above reflect exciting developments. A sampling of substantive accomplishments, presented below, attests further to that exciting growth.

Physiology, Cellular and Molecular Biology

This NSF division seeks to foster a greater understanding of the formation, structure, and function of living things, from molecules to entire organisms. Biologists have been able to study fundamental mechanisms with increasing success, armed with the new tools of genetic manipulation and molecular analysis. These techniques are the driving forces behind research in all areas of biology. They have helped to relax the once rigid boundaries that defined the life sciences, and those separating biology from other disciplines and technologies. These new approaches have brought new opportunities for scientists. Because the molecular techniques offer a means to isolate single genes from the thousands in a cell, we can now study the basic components of inheritance.

To a large extent, success in contemporary biological research depends on instrumentation and related resources. To meet this need, NSF's investment in such research equipment rose by nearly half last year, from approximately \$10 million in fiscal year 1983 to nearly \$15 million in fiscal year 1984. Much of this increase was for costly instrumentation—laser assemblies, cell sorters, gene synthesizers, electron microscopes,

magnetic resonance spectrometers, fluorescence spectrophotometers, and computers—in laboratories that serve groups of biological scientists.

In recent developments, for example, the use of so-called soft x-rays (0.1 to 10 nanometers) instead of visible light as the radiation source for microscopy offers tremendous advantages in studying the fine structures of cells. This technique produces high-contrast images for analysis and simplifies the preparation and preservation of biological materials for microscopic study. In addition, NSF has supported the substantial modernization of standard equipment in a number of grantee laboratories.

Young, well-trained scientists in both the biological and physical sciences are needed for the continued advancement of plant science. Thus NSF aided 20 new postdoctoral research fellows in plant biology during fiscal year 1984. They joined the 24 initiated in 1983, the first year of an effort to encourage research careers in basic plant science.

There have been important strides in plant genetics in particular. Key elements of maize, for example, have been cloned and sequenced, and their relationships to other mobile DNA segments have been

demonstrated. The Cold Spring Harbor Laboratory launched a major expansion of its research in molecular plant genetics, with aid from NSF. In addition, studies of the plant genus *Arabodopsis* have led several scientists to believe that it may represent the simple model plant system for molecular and genetic studies.

Arabodopsis has a number of advantages. It has a short life cycle of four to five weeks from seed to seed and can be grown aseptically in culture. In contrast to most higher plants, its genome is small and simply organized. Moreover, a number of mutants of the plant are available for comparative research. For these reasons, several molecular biologists have begun research with this plant.

Several workshops contributed much to research efforts in the life sciences. Examples:

- Scientists from small colleges helped NSF staff deal with problems in supporting biological research at predominantly undergraduate institutions.
- A workshop on the "Chemistry of Life Processes" brought together 12 leading chemists and biologists to explore opportunities for collaborative research. They developed a new NSF program announcement, published and distributed in the fall of 1984.
- Another workshop topic was the need for, and implications of, advanced computers in contemporary biological research.
- A seminar sponsored by NSF and the U.S. Department of Agriculture focused on new research directions in plant hormones.

The use of new molecular biology techniques, the availability of instruments, and the influx of creative young scientists into the laboratory are essential to progress in physiology and in cellular and molecular biology. The research accomplishments described here are only a sampling of the many approaches and directions available to life scientists today.



Model Plant. The plant *Arabidopsis* offers several advantages for molecular and genetic studies. Shown here are two pots — one with 8 plants, the other with about 50. Those in the crowded pot are not as tall but have about the same number of seed pods. Even though the plants are only 32 days old, some of the older pods have already been harvested.



Chemical Enhancement of Blood

Hemoglobin, the blood component that carries oxygen from the lungs to the body's cells, can be modified chemically so that it releases oxygen more readily.

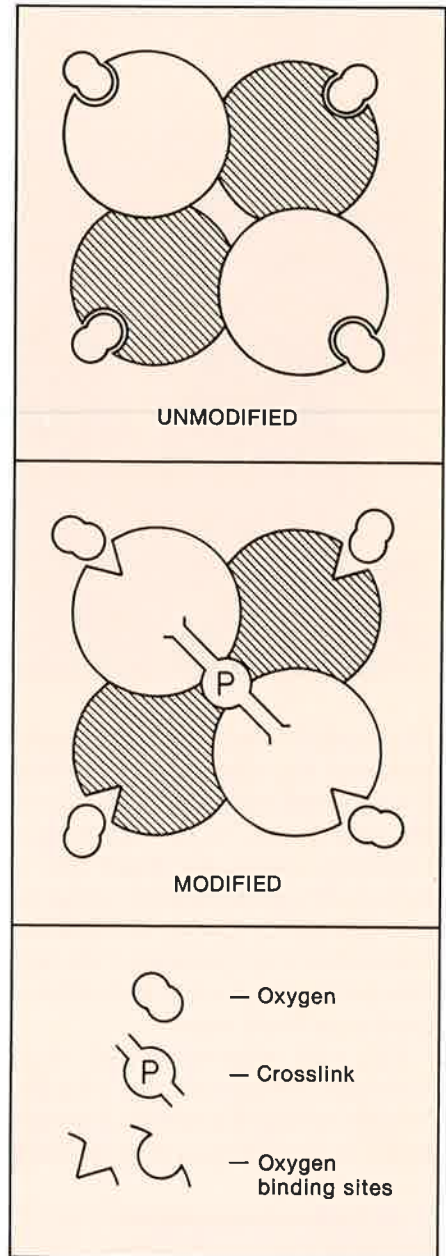
This finding from basic biochemical research has major implications in several areas. Among them: preserving organs and tissues more efficiently for possible transplants, supporting normal heart functions during low-temperature open-heart surgery, and offsetting the effects of other activities that tax the blood's capacity to carry oxygen.

Researchers Reinhold Benesch, Ruth Benesch, and Lubos Triner at Columbia University have shown that the hemoglobin molecule will release oxygen more readily if two of its four subunits (loosely joined chains of amino acids) are strongly fixed to one another by a special cross-linking agent that contains phosphate. When a pair of subunits becomes strongly bonded by the chemical treatment, the oxygen-binding properties of the molecule change.

Early test-tube studies with the cross-linked hemoglobin led the investigators to predict that it would yield its oxygen more readily to cells than would normal hemoglobin. This hypothesis was confirmed in experiments where either ordinary or cross-linked hemoglobin flowed through a rabbit heart. After 90 minutes, rabbit hearts pumping cross-linked hemoglobin were more than three times as efficient in their ability to contract as were hearts pumping blood with normal hemoglobin. Further, the improved oxygen unloading occurred in a number of circumstances: at higher tissue-oxygen pressures than with normal hemoglobin, at different heart and blood-flow rates, and even at low temperatures.

Surviving Dehydration

Even though water is generally required for life, especially for the maintenance of cells and tissues, some animals can survive the removal of nearly all their intracellular water. These organisms ex-



Cross-linking releases oxygen. The top figure shows the normal binding of oxygen by hemoglobin. But when two of the four subunits of the molecule are chemically cross-linked, oxygen tends to escape.

ist in a dormant, dehydrated state during drought or periods of low temperature; when water again becomes available, they take it up rapidly and swell, then resume an active metabolism.

One group of organisms that can survive complete dehydration is the soil-dwelling nematode, a small worm of considerable agricultural importance.



Blood enhancers. The basic biochemical research of three Columbia University scientists — Rudolph and Ruth Benesch, seen here, and Lubos Triner — on the release of oxygen by hemoglobin has important implications for heart surgery.

(Bacterial- and fungal-feeding nematodes can be beneficial, while those that eat plants may harm crops.) Zoologist John Crowe, at the University of California, Davis, has found that, in order to survive dehydration, nematodes must dry slowly. During this time they manufacture large quantities of the sugar trehalose, a more complicated version of glucose, or blood sugar.

The cell membranes of these nematodes remain intact after complete, but slow, cellular dehydration. The membranes do not undergo a phase transition

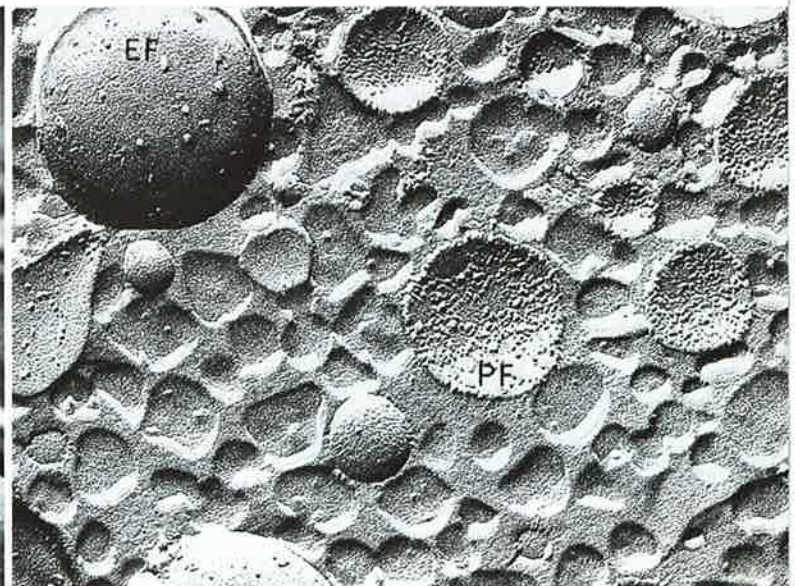
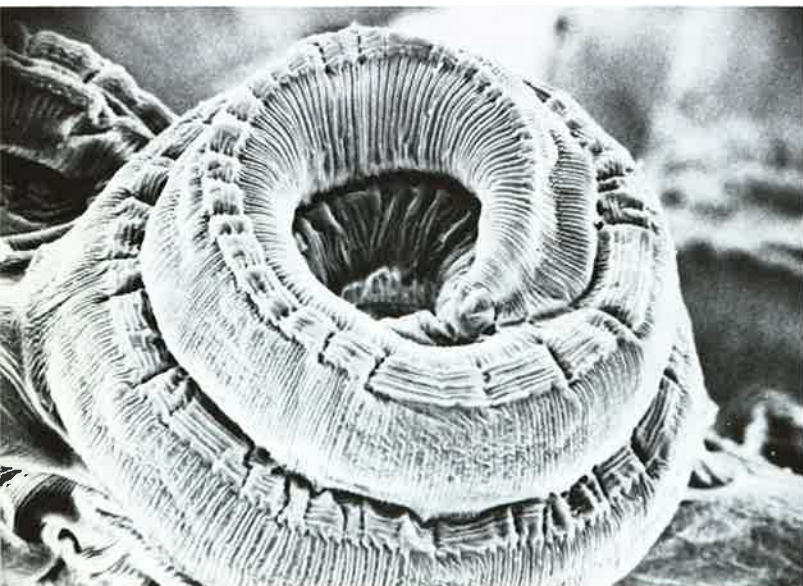
from the normal fluid state to the more rigid gel state, as is seen in the cell membranes of organisms not resistant to dehydration. Because such phase transitions are avoided, the cell death that normally accompanies changes in membrane state does not occur. Crowe's research suggests that interactions between trehalose and fatty substances in the cell membranes called phospholipids prevent damage by directly inhibiting those crucial phase transitions.

Since nematodes are such small animals, sufficient quantities of cell mem-

brane cannot be obtained to test directly the effects of trehalose on membrane structure *in vitro*. Thus Crowe used the muscle cells of lobsters, another invertebrate organism, as a model system. These cells are rich in a membrane component called the sarcoplasmic reticulum, which can be isolated in large quantities. With this model membrane preparation, he has shown that, among a series of carbohydrates, trehalose is the most effective in preserving membrane structure in the absence of water. The sugar affords this protection even for the membranes of lobster muscle cells, which normally do not tolerate dehydration.

These studies provide, for the first time, a molecular mechanism that ex-

Life without water. John Crowe of the University of California, Davis has shown how some kinds of life can survive dehydration for decades. Without water, these animals, called nematodes, assumed a tightly coiled configuration (bottom left). The micrograph shows membrane vesicles. The concave surfaces (PF) have many protein molecules, believed responsible for the uptake of calcium (which allows muscle relaxation); the convex surfaces (EF) have fewer molecules. During dehydration the vesicles fused, producing the large ones shown at left on the next page. When dried in the presence of the compound trehalose and then rehydrated, the vesicles appeared similar to the original ones in size and particles were restricted to the concave surfaces. This research may ultimately yield important uses for the preservation of intact cells or perhaps even organs.



plains the survival of dehydration by a wide range of living organisms. Such tolerance is also found in bacterial and fungal spores, in the seeds of higher plants, and in the dormant stages of many small animals. Trehalose is present in high concentrations in many of these organisms and may be a universal means to resist drought.

This research might be especially useful by suggesting ways to enhance the long-term storage and preservation of cells, tissues, and organs. The results may also contribute to the further development of technology to preserve food and drugs for human consumption, perhaps through development of a trehalose additive.

Biochemical Catalysis: New Insights

Since the beginning of this century, a fundamental dogma of biochemistry has been that enzymes, which catalyze all biological reactions, are made of proteins. As each newly discovered enzyme was isolated and crystallized, it was found to be a protein. This confirmed the belief that proteins were the single essential macromolecule responsible for biochemical catalysis.

The first observations that cast some doubt on this assumption came from investigations at the University of Colorado. Now research by Sidney Altman at Yale University suggests that nucleic

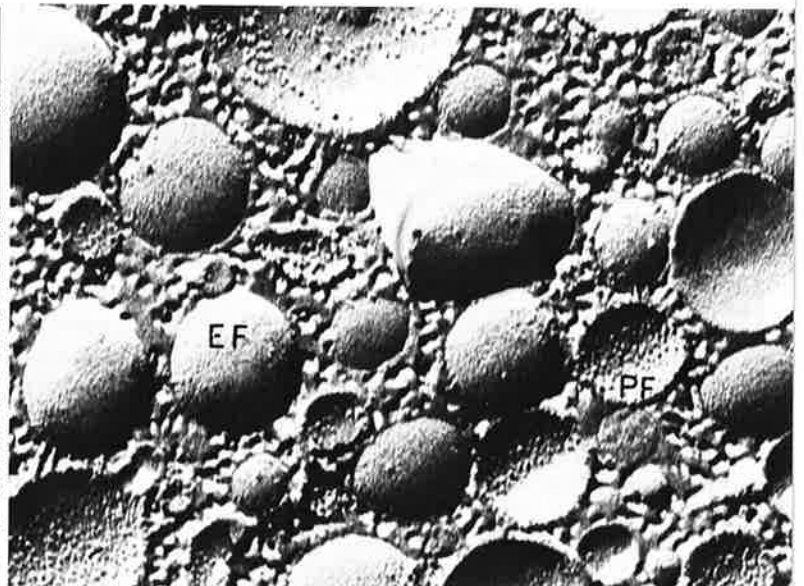
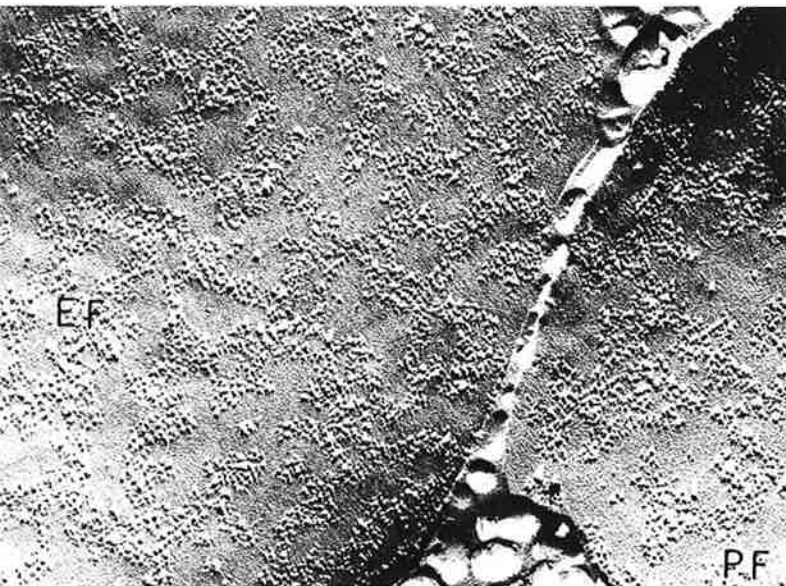
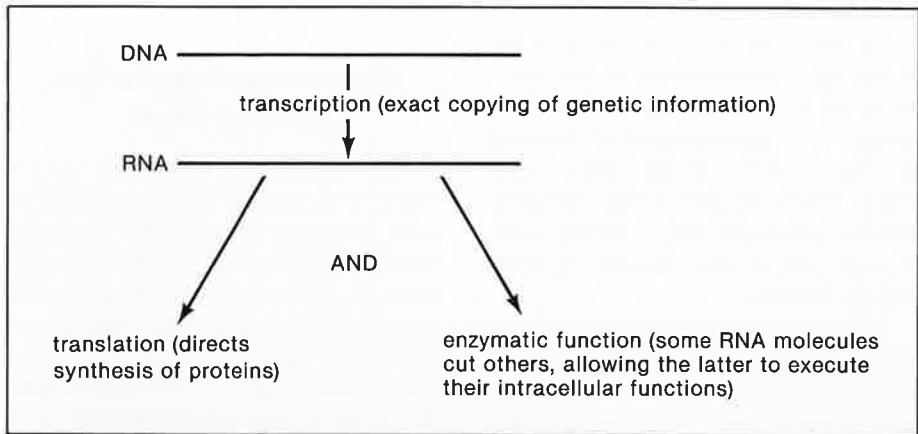
acids, specifically ribonucleic acid or RNA, can also play an important role—similar to that of enzymes—in certain biochemical reactions. Altman's findings have implications in at least two areas: hypotheses about the molecular biology of life's origins, and applications in biotechnology that hinge upon an understanding of biochemical catalysis.

Altman and his colleagues have found that the catalytic activity of the enzyme ribonuclease P, a 7-to-1 mix of RNA to protein, actually resides in the RNA. This enzyme processes gene transcripts, removing extraneous material from one end of precursor transfer RNA and cleaving another precursor. Altman has shown that the RNA component of ribonuclease P

will cleave precursor RNA by itself, although at a much reduced rate. It is reusable and thus a true catalyst. True catalytic activity may also be inferred from the RNA's other demonstrated properties, including specificity, saturability, and responsiveness to manipulations of temperature and other factors.

Yet to be explained is the role of the protein component of ribonuclease P. One possibility is that the component holds the floppy RNA molecule in the proper configuration for catalysis of the reaction. Without the protein, the RNA would be in that configuration only a fraction of the time; although the reaction would proceed, it would do so much less efficiently.

New light on catalysis. DNA is the carrier of genetic information; it is copied into RNA, a polymer very similar in its chemical nature. RNA was thought to be only an intermediate stage in allowing the cell to use the information in DNA to make proteins. An additional function for RNA, as indicated in the figure, has recently been discovered.



These findings have stimulated a move to reexamine the role of both RNA and protein in catalysis. Most discussions of the origin of life acknowledge the primacy of nucleic acids as the self-replicating molecules. The new evidence sets a precedent for considering that RNA, even in the absence of protein, was the earliest self-replicating biochemical

system. Such a primordial role for RNA may be reflected in present-day coenzymes, which could be vestiges of RNA enzymes. As protein synthesis evolved, most of the structure of the RNA enzymes might have been lost, with only the coenzymes—the active site of the earlier enzyme—remaining.

taries. The Andean drainage provides the nutrients at rising water that support primary production on the floodplain (varzea) at falling water. The varzea in turn is thought to export organic matter downriver.

This view of the Amazon is based on isolated studies of specific sites. Now the CAMREX project (Cooperative Amazon River Experiment) will provide for the first time a quantitative long-term analysis of the ecosystem's water, sediment, and chemical balances (both dissolved and particulate). This systematic study of the basin's biogeochemistry is part of a cooperative U.S.-Brazilian research program led by Jeffrey E. Richey, University of Washington, and Eneas Salati, University of São Paulo, Brazil.

A series of nine cruises in 1982-84 sampled 18 mainstem and tributary stations. The data collected on these cruises indicate that the Amazon is a dynamic river system, both physically and biogeochemically. Interaction with the tributary catchments and varzea produces consistent yearly cycles that are closely coupled to the annual fluctuation in the main channel's rate of discharge. Furthermore, these cycles suggest that the Amazon may function somewhat differently than current theory indicates. Some important lessons already learned:

- Compositions of organic matter and nutrients exported from each tributary catchment are quite different from one another and from the mainstem. This suggests that nutrient cycling and input from nearby land areas are not as uniform and strongly coupled as previously thought.
- According to nutrient data, the varzea may function as a source, rather than a sink, for nitrate and perhaps other nutrients. The excess nitrogen (N) may be provided through N-fixation by plants during low water.
- Although the carbon measured seems to be dominated by land inputs, the origin of the material consumed by respiration is not known.

Biotic Systems and Resources

Research in biotic systems explores interrelationships among organisms in the context of their natural environment. Some scientists perceive these interrelationships on a global scope, as in the biogeochemical study of carbon transport and metabolism in the Amazon River, described later. Awareness of the increasing concentration of carbon dioxide in the atmosphere has quickened the interest of biogeochemists in studying the fate of carbon in the earth's major rivers. While the carbon metabolism of land and oceans has been relatively well-studied, that of the Amazon River is largely unknown.

Other biotic research requires a sweeping view of the earth's history. Studies of animal life in marine caves on opposite sides of the Atlantic Ocean reveal a similarity between crustacean fauna. This similarity arises from the fact that the African and North American continental plates were much closer together some 150 million years ago.

Finally, ecologists and systematists are making extensive use of computers in approaching a variety of problems; some computer-aided studies in systematic biology are summarized below.

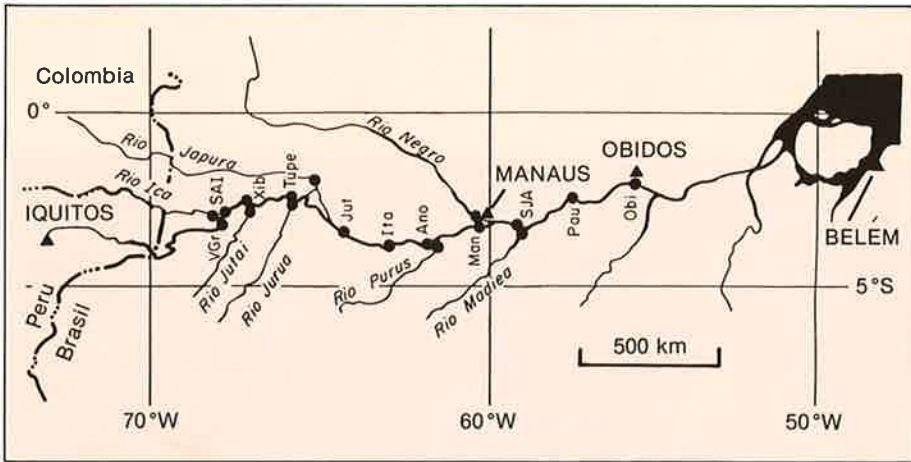
Ecological research won additional support in FY 1984 through the Presidential Young Investigator Awards. One of these recognized the outstanding accomplishments and promise of May R. Berenbaum, University of Illinois, studying plant-animal interactions, and

another award honored the achievements of Daniel I. Rubenstein, Princeton University, in behavioral ecology. In addition, NSF awarded 19 postdoctoral research fellowships to scientists working on a variety of research topics in biotic systems.

Biogeochemistry of the Amazon River

The Amazon basin and its river system represent an exciting challenge for ecologists interested in land-water interrelationships. The basin is a tropical forest of over six million square kilometers that discharges 20 percent of the river input to the oceans. Because the basin is essentially undisturbed, we can determine how this kind of ecosystem functions in a natural state. Our current understanding of the behavior of unperturbed rivers does not extend beyond those of medium size. The sheer magnitude of the Amazon region is such that the river has an impact on global climate cycles.

The Amazon basin can be thought of in the same biogeochemical terms as a more traditional "small watershed." The prevailing view of the basin is one of a uniform, dense forest growing on highly leached, impoverished soils. Forest production is maintained through rapid and efficient recycling independent of the mineral soil. The chemistry of the river's mainstem is then thought to be regulated by the inputs from the respective tribu-



CAMREX stations. VGr = Vargem Grande, SAI = Santo Antonio do Ica, XIB = Xibeco, Tupe = Tupe, Jut = Jutica, ITA = Itapeua, Ano = Anori, Man = Manacapuru, SJA = São José do Amatari, PAU = Paura, and Obi = Obidos. Points on Amazon River tributaries indicate stations there.

It is probably tied to the river's erosion and deposition cycle. If so, interactions across the river-land interface may dominate the chemistry of major rivers.

Continuation of the pioneering collaborative research on the Amazon—and extension of this approach to other major river systems—will consolidate our understanding of the global dynamics of elemental cycles.

Ancient Crustaceans in Marine Caves

Marine speleologists, exploring underwater caves on both sides of the Atlantic Ocean, have discovered an array of bizarre primitive crustaceans believed to constitute an entirely new class of animals. The new lineage was named *Remipedia* in 1981 by Jill Yager, St. Paul's College, Freeport, Bahamas. It was first suspected on the basis of a few specimens that Yager discovered during scuba dives into Lucayan Cavern near Freeport.

Later dives have revealed several species of *Remipedia*. Yager has explored other Bahamian caves, and Thomas Iliffe of the Bermuda Biological Station has found the species in Jameos del Agua cave, a seawater-flooded lava tube in the Canary Islands. All the species found show the reduced body pigmentation and eyeless condition typical of many cave-

adapted animals. In addition, *Remipedia* retain a primitive body construction remarkably similar to crustacean fossils from the Carboniferous period (about 300 million years ago).

Despite this primitive body plan, *Remipedia's* mouth parts are highly specialized and used in a method of feeding otherwise unknown among crustacea. It feeds much as a spider does, by injecting a fluid through the cuticle of its prey (usually a small shrimp), sucking out the soft tissues, and then discarding the empty cuticle. The paired mouth part called

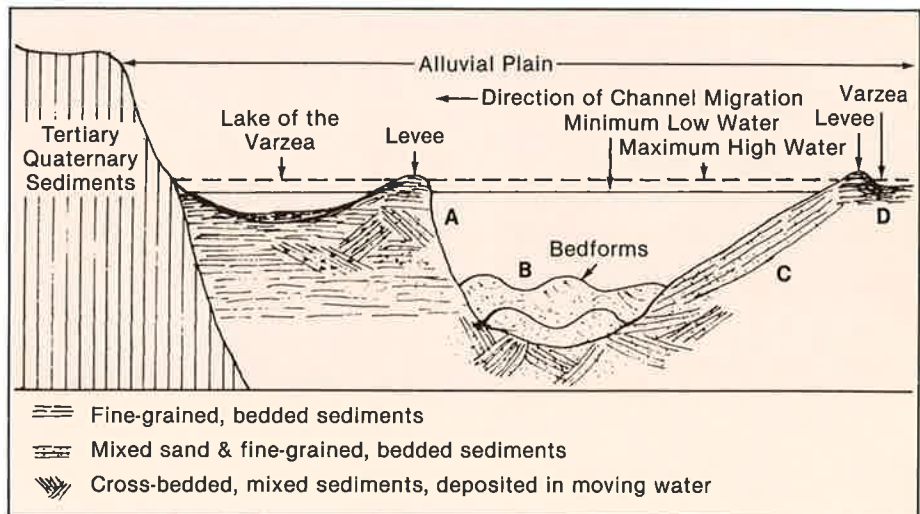
the maxillule is positioned near the mouth in the place occupied by the mandibles in most crustaceans—a lobster, for example.

At this writing Yager and Frederick Schram, a paleontologist from the San Diego Natural History Museum, are reconstructing the life cycles of the organisms and investigating their morphology and physiology.

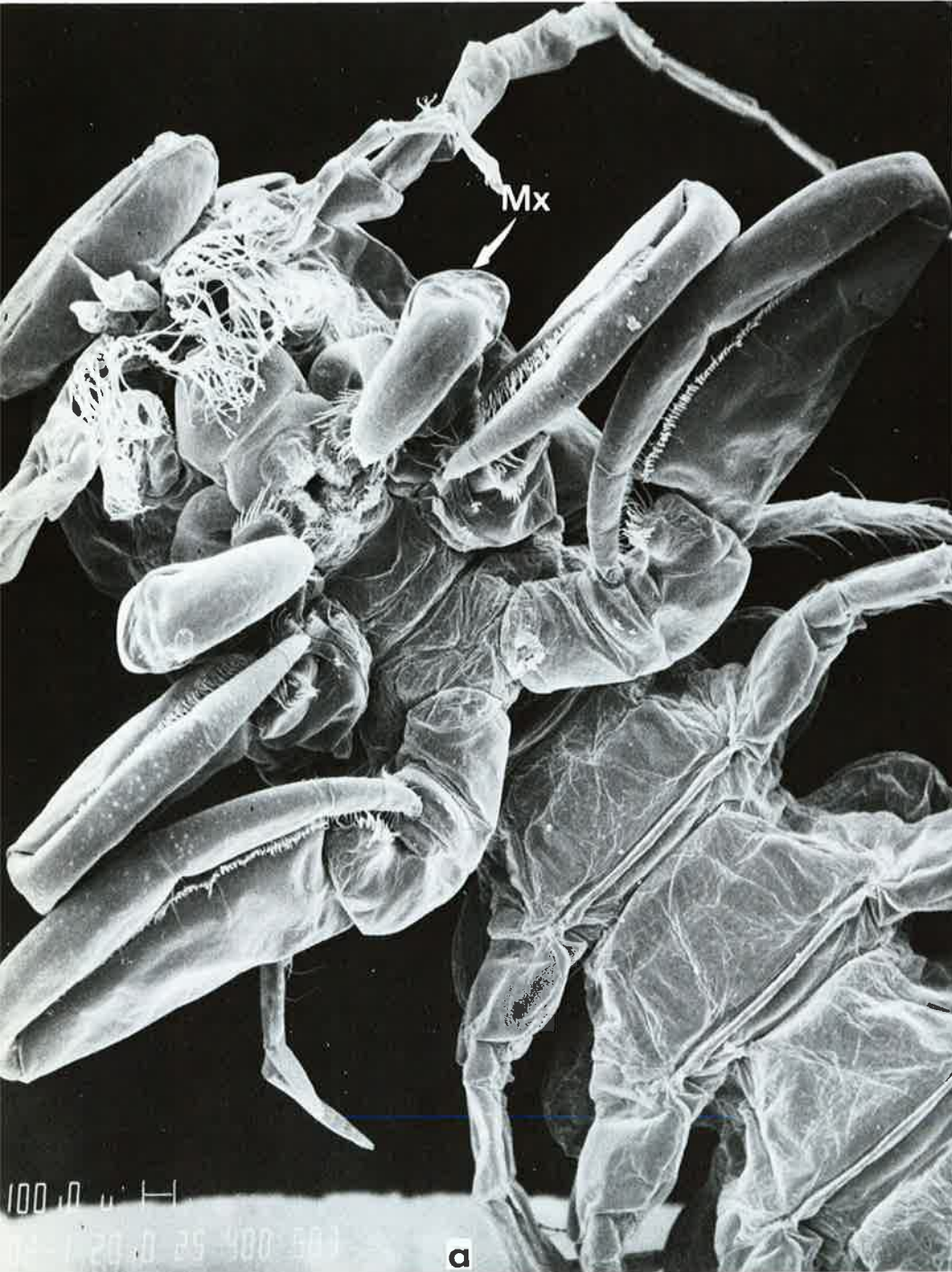
Caves often provide habitats that are home to relict organisms, survivors from previous eras which cannot live outside the cave environment. Thomas Iliffe and his colleagues have made detailed comparisons of fauna in both the Bahamian caves and the Canary Islands lava caves. These widely separated fauna are very similar, containing, in addition to the *Remipedia*, several other endemic genera and species in common.

The cave fauna also show great similarities to fossil communities from marine rocks deposited over 150 million years ago in the Tethys Sea. About 250 million years ago the earth's continents converged to form the supercontinent of Pangea. Subsequently, continental drift forces caused the continents of what are now the eastern and western hemispheres to separate, forming the Tethys Sea between them. A unique fauna inhabited this sea, and Iliffe believes that caves

Amazon River (schematic cross-section), A, Erosion remobilizes buried and living carbon into river. B, Sand transport constructs midchannel bars, point bars, and islands. C, Deposits of suspended sand create bars on floodplain margin. D, Suspended sediment from main channel drops out of suspension on floodplain, depositing itself in lakes and on levees.



Remipedia. Scanning electron photomicrograph shows the ventral surface of a remipedian crustacean. Note the square, central mouth fringed with bristles. The paired mouth parts called maxillules (Mx) play a primary role in feeding. After the prey, usually a small shrimp, is grasped by the several pairs of appendages, the tip of the maxillule, enlarged in the other photos, injects a fluid into the prey. The remipede then sucks out the soft tissue. (Note scale: One micron equals one thousandth of a millimeter.)



were refuges for its members as the continents continued to drift apart.

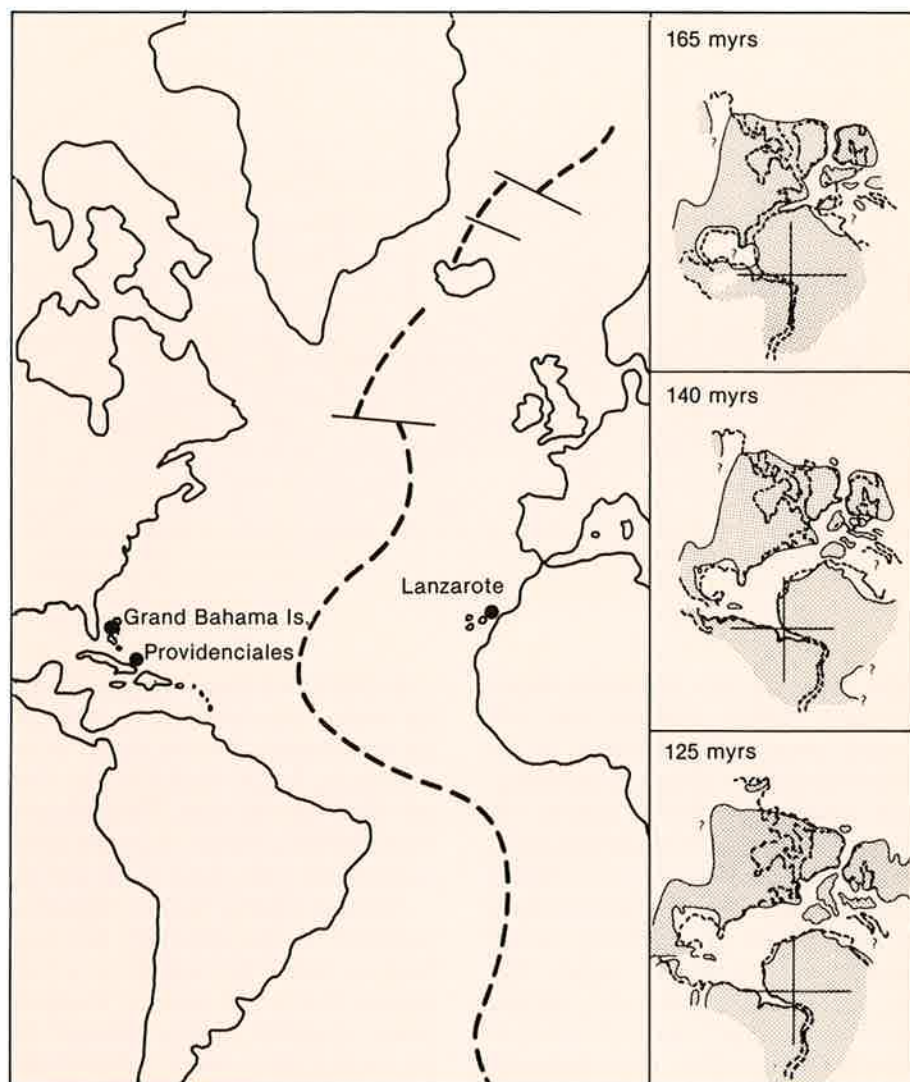
This model explains the wide separation of very similar but quite restricted cave fauna on both sides of the Atlantic Ocean today. Similar marine caves are on the other oceanic islands, such as the Palau group in the western Pacific, and analyses of their fauna are under way at this writing. Scientists hope that such studies will help interpret the complex biogeography and plate tectonics of the Pacific basin.

Computers in Systematics

Computers have contributed to recent gains in the evolutionary meaning of shape and in image analysis, two areas of systematic biology. For example, computers have greatly helped Cornell University's Karl J. Niklas in his study of the evolutionary and ecological determinants of shape in plants. He has analyzed the adaptive significance of seed-cone morphology in living and extinct wind-pollinated plants (mostly gymnosperms—conifers, cycads, and their fossil ancestors). In particular, Niklas has looked at features that selectively bias the impact and deposit of pollen grains on particular cone areas. He has determined the complex aerodynamic properties and trajectories of the grains by high-speed cinematography in a specially constructed smoke chamber.

In his most important achievement so far, Niklas has demonstrated the likelihood that particular cone features—size of cone scales, angle of growth from cone axis—cause local vortices that “funnel” pollen onto particular sites in or on the cone, near the ovular (seed) chamber. This technique, which uses a color-coded video display and computer analysis, has wide applicability in scientific research; it could be used to describe any system of particle motion (airborne microbes, chemical sprays, insect flight, etc.).

Niklas has also used computers in the simulation of plant growth and the three-dimensional construction of trees. Each computer-generated “tree” can be as-



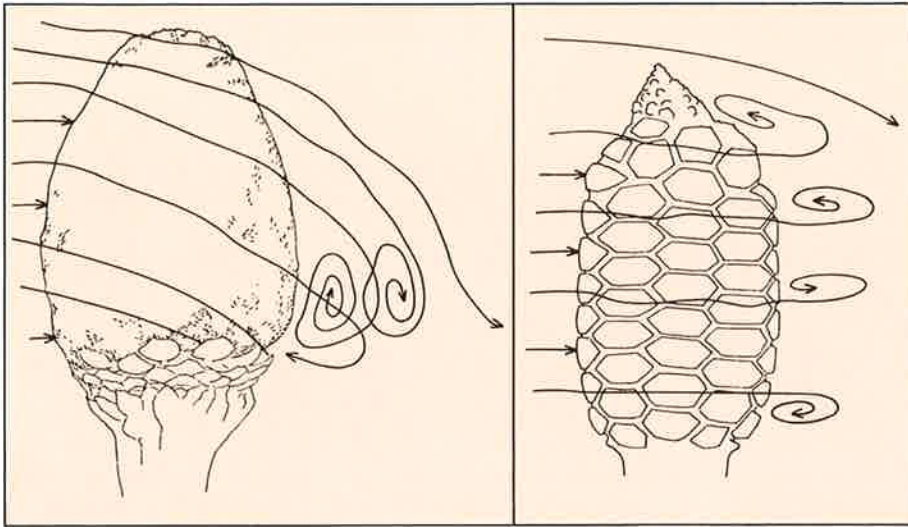
The Atlantic Ocean . . . from the Tethys Sea. The large drawing indicates the present configuration of the Atlantic, showing the three islands where *Remipedia* crustaceans are known to live in marine caves. Interrupted line traces mid-Atlantic ridge, the site of sea-floor spreading. It is offset in its course at transverse fracture zones. The panel shows three stages (165, 140, and 125 myrs or million years ago, respectively) in the enlargement of the Tethys Sea as the North American and African continental plates drifted apart. Note that the now widely separated sites with living *Remipedia* were once much closer together. These marine-cave fauna in general resemble fossil communities known from Tethys Sea deposits laid down 150 myrs. (Panel modified from Thiede, 1979)

sessed in terms of its capacity to absorb light, and it can be related to the shape of real trees. This simulation provides insights into modern-day tree ecology, as well as the evolution of plant form. Millions of years of evolutionary change can be simulated; comparisons between simulations and the fossil record offer a means to test evolutionary hypotheses.

External morphology is still the easiest and most prevalent characteristic used to

identify and classify organisms. The translation of such data to precise terms, however, is often difficult. Verbal descriptions are not amenable to mathematical analysis, and simple measurements such as ratios often miss subtle but important differences in shape.

James F. Rohlf, at the State University of New York at Stony Brook, and Fred L. Bookstein and Richard E. Strauss, at the University of Michigan, have been pur-



Aerodynamics and pollen patterns. A computer can analyze high-speed cinematography of pollen-grain trajectories in a wind tunnel and assess the significance of cone shape in two kinds of cycad. Airflow patterns are shown here for both plants.

suing alternative ways to describe shapes precisely. Rohlf's approach uses videotaped photographs, drawings, or the actual organisms—along with the mathematical technique of Fourier analysis—to describe the outlines of objects precisely. The Fourier transforms can be compared mathematically, yielding classifications of similar shapes and suggesting transformation pathways between shapes. The technique has been successfully applied to mosquito wings, leading ultimately to more knowledge about these important pests.

Bookstein and Strauss's method of image analysis uses homologous points on the perimeters of different shapes to determine the factors needed to transform one shape into the other. The method is being applied to studies of primate facial anatomy and a wide array of fish species.

Although either of these mathematical techniques could potentially be calculated by hand, the number of simultaneous factors that must be examined makes computer analysis essential for the practical application of both methods.

Behavioral and Neural Sciences

This research advances our knowledge of the many factors—biological, environmental, and cultural—that form human and animal behavior. Behavioral and neural scientists work on several levels: molecular, cellular, individual, and cultural. Their efforts fall into three categories—anthropology, cognitive science, and neuroscience.

Anthropology represents broad approaches—integrating biological, phys-

ical, and social sciences—to the understanding of human cultures now and in the past. NSF supports research in archaeology and in physical and cultural anthropology. It also aids the preservation of, and improved access to, important collections of artifacts and other research findings.

Because accurate dating of bones and artifacts is vital, NSF has begun an annual archaeometry competition to

encourage research leading to better dating techniques. The competition also will support laboratories that date artifacts discovered during NSF-funded expeditions.

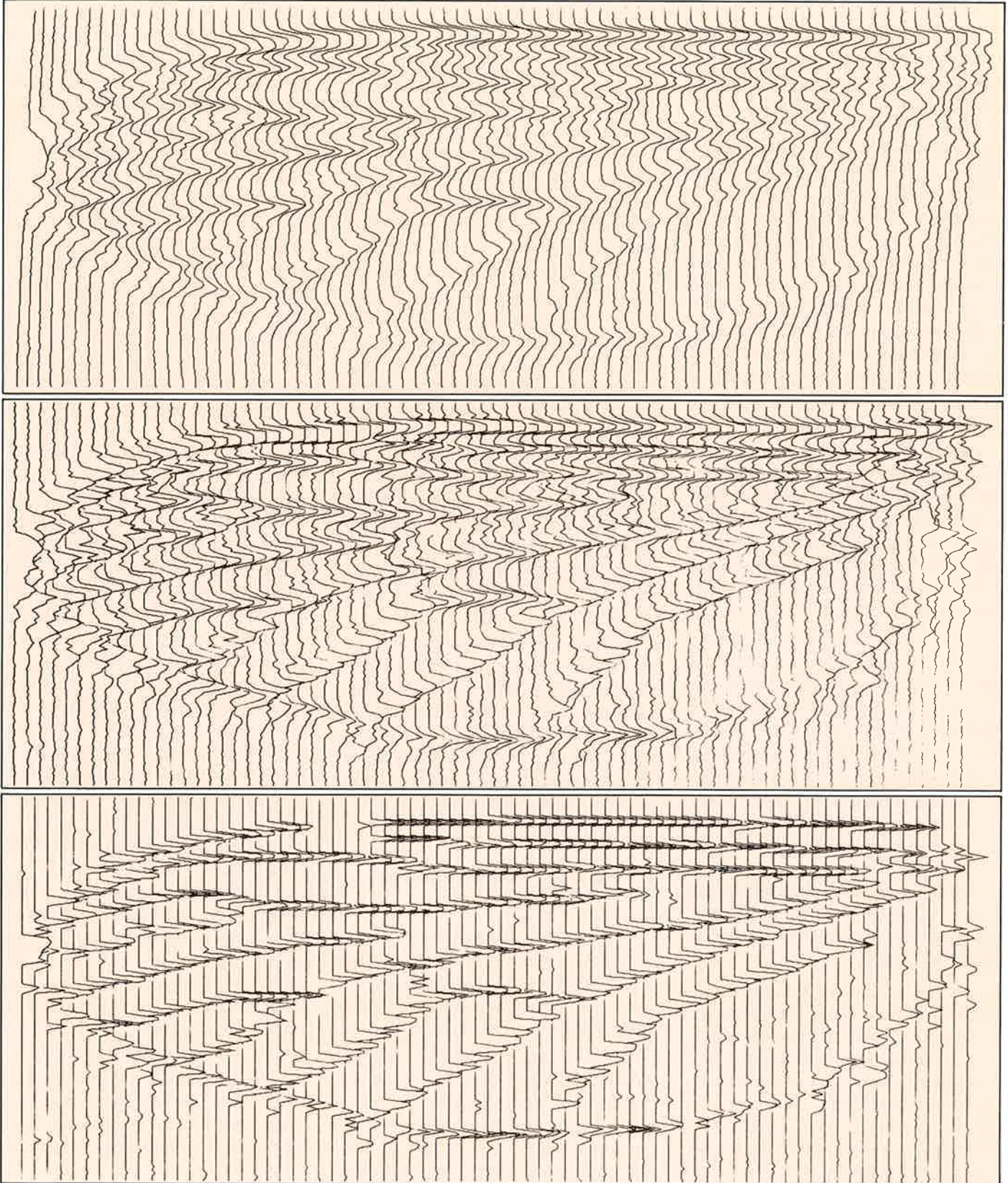
Cognitive science deals with how humans learn, remember, and retrieve information from memory; on the properties of language; and on broader human behaviors, including developmental processes. For example, Elizabeth Loftus at the University of Washington has been looking at the ways people store representations of complex scenes and events they have viewed. This work has been useful in courtrooms when eyewitness testimony is a key factor in a case.

Mary Potter at the Massachusetts Institute of Technology has been working on a new way to present written text, a technique that might be used to increase the reading speed of those who must digest vast quantities of information.

Research on social cognition—a complex set of interconnected cognitive rules and strategies that are sensitive to situational contexts—is providing new ways of looking at other psychological phenomena. For example, research has documented that individuals' feelings of having or not having control over important outcomes in their lives play a crucial role in coping with difficult problems. A perceived lack of personal control over negative events may lead to clinical depression.

Research in the neurosciences examines nerve cell action; the anatomy, physiology, and biochemistry of the nervous system, including its growth and development; and the function of the brain and nervous system in producing and controlling behavior. Because of rapid growth and advances in the neurosciences, NSF restructured these programs in 1984, aiming to foster and monitor research on the nervous system more effectively. Three new programs set up during the past year were developmental neuroscience, integrative neural systems, and molecular and cellular neurobiology. All represent specialized areas at the forefront of research.

Mosquito wings. Various methods of a mathematical technique called Fourier analysis were used to depict wing shape. This image-analysis research gives scientists key information about mosquitos — possibly contributing to better control of those pests in the future.



First Humans in the Western Hemisphere

The question of when human populations first arrived in the Western Hemisphere has long been debated among American archaeologists. There is general agreement that all of our biological antecedents—including anatomically modern *Homo sapiens*—evolved in the Old World. The populations that first occupied the New World moved out of eastern Asia, crossed over into western Alaska during a period of low sea level, and from there moved south into continental North America. Accurate dating of these migrations is vital, since the timing of the earliest human arrivals in the New World is a key to many issues in anthropology—among them the formation of Native American languages.

An important piece of evidence has been age determinations made directly on New World *Homo sapiens* skeletal materials. Until the mid-1960s, carbon-14 dating techniques pointed to the earliest presence of humans in the New World at about 10,000 B.C.E. (Before Common Era).

In the early 1970s, carbon-14 estimates on various organic fractions of human bone suggested that the upper limit should be adjusted to the 20,000 to 25,000 B.P. (Before Present) range. Then a new method of bone dating, called amino acid racemization (AAR), indicated still older dates for early man in North America. Skeletons from the southern San Francisco Bay region, southern California, and the Imperial Valley in southeastern California fell into the range of 20,000 to 70,000 B.P. when dated by AAR, further stimulating the dating controversy.

Archaeologists were exceedingly skeptical of these dates. Archaeological context was lacking, and morphologically two of the three California skeletons were fully modern *Homo sapiens*. If correctly dated, they would have been among the oldest of directly dated modern human skeletons in the world—predating the generally accepted age for the

first appearance of anatomically modern human populations in the Old World by as much as 30,000 years.

Recent studies by NSF-supported research groups have reevaluated the ages for most of these purported Pleistocene New World skeletons. The studies were possible largely through development of accelerator mass spectrometry techniques for carbon-14 analysis. These techniques permit the measurement of milligram amounts of organic extracts from bone.

Collaboration between the NSF Regional Center for Radioisotope Analysis, at the University of Arizona, and the Radiocarbon Laboratory, at the University of California-Riverside, has produced direct carbon-14 measurements on several New World skeletons. In each case, the age of an organic extract from the skeleton did not exceed late Pleistocene or Holocene; that is, the skeletons were all less than 10,000 to 11,000 years of age by carbon-14 dating. In some cases, such as the Sunnyvale skeleton from San Francisco Bay, the correction of the AAR-deduced age is from 70,000 to 5,000 years!

Radiocarbon data from other accelerator groups in Canada and England confirm that all New World human skeletons previously dated to the Pleistocene are, in fact, of late Pleistocene or Holocene age. Currently, the oldest directly dated human skeleton shows a carbon-14 age of about 11,000 years B.P.

How Nervous Systems Develop

New techniques to analyze individual nerve cells and their growth patterns have added much to our understanding of nervous system development, especially at the cellular and molecular level.

A good example of this is work by Stanford's Corey Goodman, winner of NSF's Alan T. Waterman Award in 1983. He is interested in how the intricate connections of the nervous system are laid out, and he has chosen the developing

grasshopper for his work. The grasshopper embryo is ideal because it is transparent, and it has identifiable cells that can be manipulated during development. Using a specialized optical system, Goodman can observe individual cells and their processes. He also can impale the cells with microelectrodes for dye injection and physiological study.

Nerve cells (neurons) send out long structures, or axons, which are equipped with specialized contacts called synapses. Through these contacts they communicate with other neurons or organs. As the axons develop, their growing tips form specialized, transient structures called growth cones. These cones are armed with numerous filaments (filopodia), which explore the embryonic environment for certain mechanical and chemical cues.

As they move through their environment, the filopodia adhere strongly to some cell surfaces or extracellular substrates but only weakly to others. Goodman is trying to find out how the growth cones of different neurons make different choices in forming pathways when confronted with the same environment.

Using powerful new techniques, Goodman and his coworkers have labeled individual axons and their growth cones in the embryonic grasshopper. As development progresses, individual axons come together to form bundles. In this highly ordered process, the filopodia of a growing axon make very specific choices as to which axon bundle to join—although they may temporarily grasp many different bundles.

Goodman's observations have led him to believe that early-developing neurons consistently establish the same type of axonal pathways and somehow "label" surfaces as they move along. Later axonal growth cones then sample these labeled surfaces and make pathway choices leading to selective bundle formation.

This research tells us much about the way neurons find and interact with other cells. It holds promise for an understanding of overall development in the nervous system.

Social and Economic Science

Although the social and economic sciences include several separate disciplines, they share a common research orientation. Work in these sciences focuses on social and economic systems, their organization and change, and on the behavior of individuals and groups in changing social and economic contexts. The scope of this research ranges from studies of market behavior and decision making in a business firm to voting behavior and population dynamics.

Most NSF-supported projects in the social and economic sciences can be grouped into three categories: basic research, data development and dissemination, and measurement and methodological research. The first of these involves empirical testing of social and economic theories across a broad range of topics. Because of the widespread and changing interaction of so many social and economic variables, basic research in these sciences is technically complicated and requires extensive and timely data collection and analysis.

Given the importance of quantitative data for testing scientific theories, data resources can be called the measurement instruments of the social and economic sciences. Data are collected by social and economic scientists, by governments, and by private firms and organizations. In general, what is collected for other than scientific purposes must be prepared in a form suitable for scientific analysis before it can be used for research.

Research in the third area, measurement and methodological research, focuses on the development of analytical methodologies that can deal with change over time and with what seems at first to be unpredictable behavior. Scientists try to examine specific ways to measure social and economic behavior and change when the key variables cannot be directly observed or are subject to error.

Within these broad general categories are individual projects, as described

here: research on patterns of technological innovation in the field of lasers, and on the effect of credit (as compared to money) on national economic activity.

Masers and Lasers

Does science precede technology, or technology science? This issue has been the subject of intense debate among historians, economists, and science policy makers, but that debate often misses the real processes of development and innovation in both science and technology. The answer is "yes" and "no" to both questions. Science and technology do mutually interact, but they do so in a social, economic, entrepreneurial, institutional, and political environment that pushes or pulls their development in a number of directions. Joan Bromberg illustrates the interaction of all these factors in her history of masers and lasers.

The laser (light amplification by stimulated emission of radiation) is an ideal model for looking at the forces that have shaped contemporary high-tech industry. Its history goes back to 1916, when Albert Einstein first proposed a theoretical model for stimulated emission of radiation. In the 1920s and 1930s quantum theory arose, and in World War II many physicists worked on developing radar. They came out of the war with a stock of surplus radar equipment and, through their acquaintance with electrical engineering practice, they had new methods to attack problems.

The new approaches spawned or greatly animated fields such as nuclear and electron magnetic resonance and microwave spectroscopy. The scientific study of resonances (the transitions between quantum mechanical states) in turn led to quantum electronics—the use of quantum mechanical resonances as elements in electric circuits. Resonances were also used in inventing the maser, the parent to the laser.

According to Bromberg's study, the maser might never have developed had it not been nurtured in a university setting. It seemed too farfetched an idea to win a go-ahead from industrial managers and was nursed into operation at Columbia University, where the conditions for devoting research resources were more lenient.

Early maser research also focused on the needs of the military, which considered it to have great potential for weapon systems. Thus funding for the maser's development came largely from that source. A few major industrial laboratories started research programs in this area, says Bromberg, but even in these cases, the defense establishment played a key funding role.

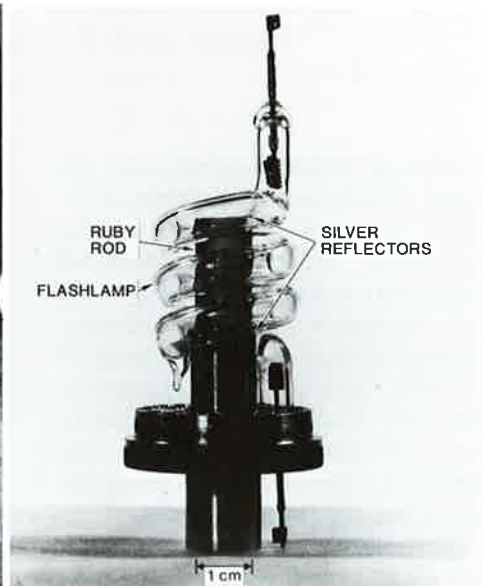
With the U.S.S.R.'s launch of *Sputnik* in October 1957, the military was shocked into making a greater commitment to innovative research and development, and the Advanced Research Projects Agency (ARPA) was set up in the Department of Defense.

With the abundance of government research funds in the post-*Sputnik* period, the first U.S. attempts to build operating lasers got under way in exceptionally affluent circumstances. A major firm, TRG, submitted a proposal to ARPA in 1958 for \$300,000 and received \$1 million instead. In 1959, the Office of Naval Research funded a critical conference dominated by papers on masers and atomic clocks. At the informal sessions, however, there were excited discussions of the new frontier, lasers.

By 1960 a successful laser was constructed at Hughes Aircraft Company. Immediately there was widespread euphoria about business prospects, and ideas for applications—some of them extravagant—blossomed. Large corporations got involved, anticipating that lasers might affect the technologies underpinning their businesses. At the same time, scientist-entrepreneurs with innovative ideas set up small businesses patterned on the solid-state electronics industry. A burst of creative scientific and engineering activity resulted. The products of this period included carbon-



Early work. An early application of solid-state masers was in radio astronomy. Here Charles H. Townes stands beside the maser amplifier for the Naval Research Laboratory radio telescope. (Photo courtesy of AT&T Bell Laboratories)



A first. Theodore Maiman built this first operating laser at Hughes Aircraft Company. (Photo courtesy of Hughes)



Laser progress. This is one of the first argon ion lasers. (Photo courtesy of Hughes Aircraft Company)

dioxide lasers, semiconductor lasers, and dye lasers that were tunable over the entire visible range.

The early laser industry, however, did not prosper, according to the Bromberg research; not until 1973 did profits begin to appear. One cause of this change was the emergence of a significant energy market in the early 1970s, when the U.S. government began to invest tens of millions of dollars in research on laser fusion and laser isotope separation.

Today, this is a billion-dollar industry. Lasers are not only creating new frontiers in medical diagnosis and surgery, they also have become commonplace in manufacturing and are used for military devices of many types. Equally important, they are making fundamental contributions to the advance of basic science and scientific measurement. The laser's history is complex, and Bromberg's study illustrates some of the many processes that help us understand the development

of contemporary science and technology.

(Ed. Note: See also "Lightwave Technology" in the Engineering chapter of this report, under Interdisciplinary Research.)

Money, Credit, and Economic Activity

During the past quarter-century, economists probably have subjected money demand to more empirical research than

they have any other single economic factor. This research has shown a dependably close, regular relationship between the quantity of money and global measures of economic activity such as gross national product. No corresponding relationship has been found for specific financial quantities other than money. Consistent with this view of the economy, the Federal Reserve System has tended to formulate policy since the early 1970s according to monetary targets, paying little attention to credit, although that approach has changed somewhat in recent times.

The NSF-supported research of Benjamin M. Friedman, at the National Bureau of Economic Research and Harvard University, has altered our understanding of the economy by going beyond money to study the parallel relationship of credit to economic activity. He found, first, that the relationship between aggregate credit and nonfinancial economic activity is just as regular and stable as that between money and economic activity. ("Non-financial" as used here excludes the lending activities of banks, insurance companies, and other credit agencies.) Second, the interest rate and the quantity of credit both represent aspects of behavior in the credit market that are important for nonfinancial economic activity. The evidence suggests, however, that

neither variable alone is adequate to convey all the information needed for macroeconomic analysis.

The stability of the credit-income relationship is striking. The total nonfinancial economy's reliance on debt, scaled in relation to national economic activity, has shown almost no trend and little variation since World War II. The individual components of this total, however, have varied in sharply different directions—both secularly and cyclically—between 1946 and 1980. In brief:

- The secular postwar rise in private debt largely mirrored a substantial decline (relative to economic activity) in federal government debt, while bulges in federal debt issuance during recessions mostly had their counterpart in the abatement of private borrowing.

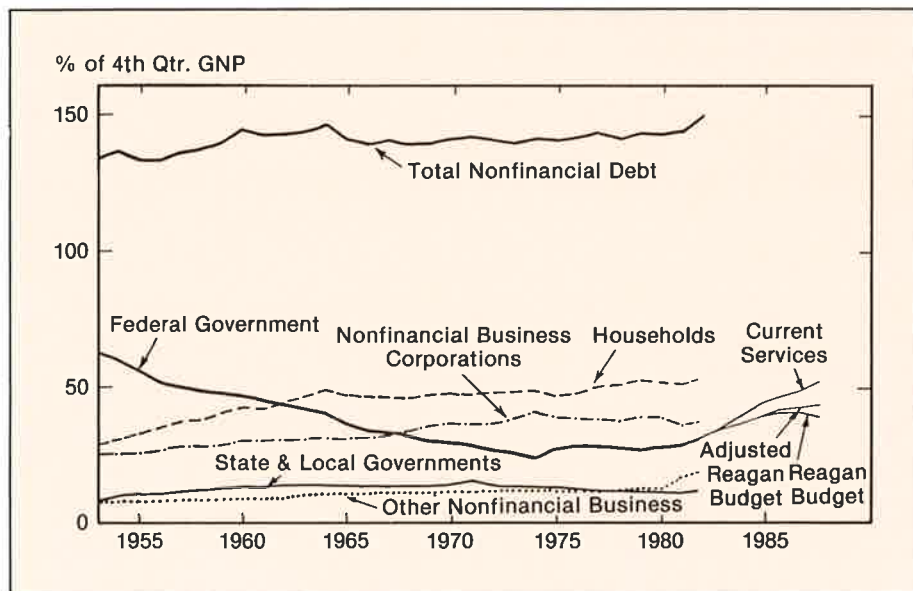
- Households almost continually increased their reliance on debt throughout this period.
- Both corporations and unincorporated businesses also held steady in debt activities, except for temporary retrenchments during recession years.
- State and local governments steadily increased their relative debt-issuing activity during the 1950s and early 1960s, but just as steadily reduced it during the 1970s.

Recently the Federal Reserve has changed its monetary policy procedures, moving from almost exclusive reliance on target growth rates for some measures of the money stock to a framework with broad-based money and credit targets that seem to agree with Friedman's evidence.

Information Science and Technology

Information science has evolved rapidly into broad, basic research on the way information is structured, represented, and used. This includes systematic research on the formal properties

and overall role of information; on biological and manmade systems that produce, store, and manipulate it; and on the effect of information technology on social and economic life.



Credit — a key economic factor.

In studying the relationship of credit and general economic activity (as reflected in the gross national product), one study showed a remarkable stability between the two — just as there is a stable relationship between money and economic activity. This figure plots data for 1951 on; it shows the year-end credit market indebtedness, as a percentage of the fourth-quarter gross national product, for all U.S. nonfinancial borrowers — and for the five categories of borrowers that together make up the total. After falling from 155.6 percent of gross national product in 1946 to 126.6 percent in 1951 and then rising to 143.9 percent in 1960, the total nonfinancial debt remained within a few percentage points of that level up to 1980, when it was 142.9 percent. (Figure after *The Changing Roles of Debt and Equity in Financing U.S. Capital Formation*, ed. Benjamin M. Friedman, Univ. of Chicago Press, 1982)

Last year NSF-funded research focused on information processing in such activities as categorizing and pattern recognition; in learning, memory, and problem solving; and in the use of "natural," or normal, language. The seeming ease of these activities in humans (and to some degree in animals) is absent in artificial systems. Progress has been made, however, in strategies for manipulating information to accomplish these tasks, and in effective ways to represent the activities in computers.

NSF also supported research in automated systems designed to augment intellectual functioning. Projects included work on the generation, transfer, and retrieval of diverse modes of information and on the interactions between users and information systems.

Scientists also assessed the impact of information on the behavior and performance of business firms and economic markets and the effects of information technologies, especially computers, in the office and home. The economic importance of those technologies as products has long been obvious, and their rapid diffusion into society has only underscored their value as commodities.

One interesting feature of information as a commodity derives from recent technological developments, such as photocopyers, videotape recorders, and personal computers. These devices make it both easy and inexpensive to produce

excellent copies of what may be called "intellectual property," while skirting copyright laws. A recent study funded by NSF looked at this "private copying"; it revealed much about the interplay between information technology, the economic aspects of information, and society's requirements for creating and marketing information products. That research is described below.

Copying Intellectual Property

Stanley M. Besen, at the Rand Corporation, developed a model to analyze the effects of private copying on the supply of information. He modeled the behavior of a typical publisher of books and journals, computer software, prerecorded videocassettes, or other forms of intellectual property. Besen examined the effect of copying on the price of originals and its impact in turn on the producers and consumers of intellectual property.

The analysis showed first that the copying can actually *increase* a publisher's profits. This occurs when (1) the technology available to copiers is more efficient than that available to publishers, and (2) the price of originals can be raised to reflect the value of the copies to be made from them.

Second, copying can adversely affect consumers. This occurs when the tech-

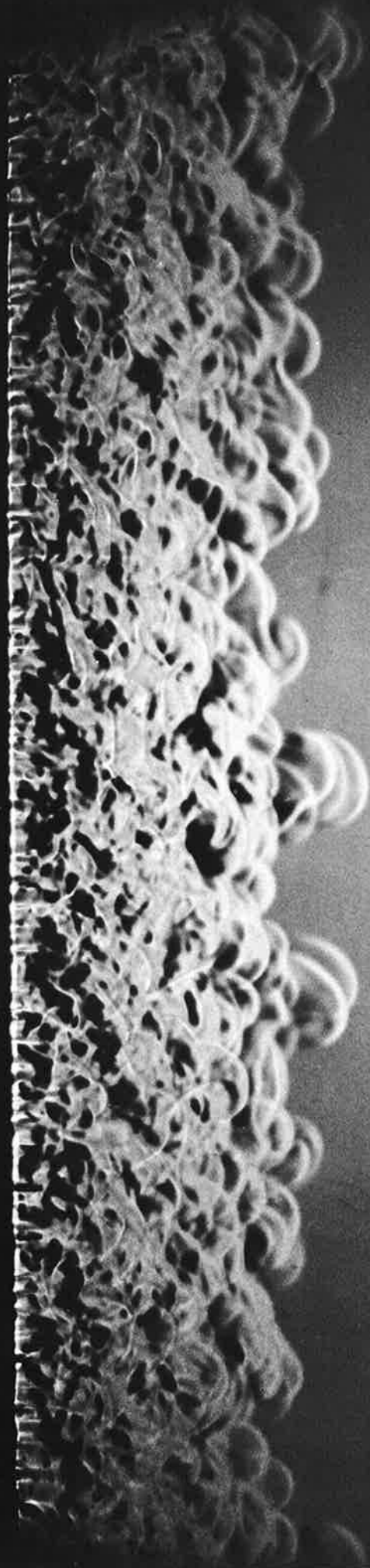
nology available to copiers is *less* efficient than that available to publishers (but not so inefficient as to discourage copying), and when consumers are unable to enter into enforceable copying agreements. Both producer and copy users share the loss created by inefficient reproduction technology, and consumers have no formal agreement they can use to force a lower price for the original.

Application of Besen's model to the question of whether all copying should be subject to copyright liability is a task for the future. His results already indicate, however, that the critical factors to be considered are the extent of copying, the incremental costs of publishing, and the costs of copying. Assessment of these factors strongly suggests that the desirability of copyright protection is likely to vary by technology.

Future work will generalize the analysis to permit (1) the number of copies per original to be endogenous; (2) publishers to adopt higher-cost technologies that make private copying more difficult; and (3) different distributions of the cost of originals among consumers. In addition, the effects of various types of royalties—for example, on copying machines or copying media—will also be analyzed.

Using this basic model, future simulations will provide quantitative estimates of the effect of copying on consumers and on producer profits.





Engineering



In the past year NSF has redefined its mission and revitalized its engineering directorate, which has unique goals and programs to strengthen the nation's research and education capability. A primary goal is to improve our research posture by supporting investigations in both the technology-driven and science-driven fields of engineering.

NSF fosters academic engineering in three ways:

- It stimulates and encourages the training of engineers at undergraduate and graduate levels through research grants and special faculty awards.
- It provides funds for equipment and facilities, to sustain and strengthen the engineering research base.
- It supports research to increase and diffuse knowledge and understanding of engineering and how it affects industrial productivity, technological innovation, and the quality of life.

In addition to these traditional programs, the Foundation—with enthusiastic support from the White House Office of Science and Technology Policy and the National Academy of Engineering—launched two key initiatives in FY 1984; they will have a significant impact on engineering research, education, and manpower. These initiatives are the Presidential Young Investigators program (PYI, mentioned in other chapters of this report) and the Engineering Research Centers.

The PYI program was created to attract some of the best engineering and scientific talent to universities, thus assuring

continued academic excellence. In fiscal 1984, 100 PYI awards went to outstanding young engineering faculty. With matching funds from industrial sources, these awards offered research support up to \$100,000 per year for five years. In addition, Research Initiation Grants were made to more than 160 new engineering faculty who had no prior research support. Both programs seek to attract highly qualified young engineers to teach in colleges and universities, and to encourage them to undertake research work early in their careers. NSF also offers small supplementary grants to university investigators who involve undergraduate students in Foundation-supported projects.

Engineering research involving expertise from various backgrounds is needed for knowledge in fast-growing technology areas. Recognizing that need, NSF asked the National Academy of Engineering to examine ways in which the Foundation could better support cross-disciplinary engineering research. The Academy's recommendations led to a new program, Engineering Research Centers, managed by NSF's Office of Interdisciplinary Research.

The goal of the Centers is to develop fundamental knowledge in engineering fields that will enhance the international competitiveness of U.S. industry. Education and research are key elements in improving U.S. industrial productivity, and

Table 3
Engineering
Fiscal Years 1983 and 1984
(Dollars in Millions)

	Fiscal Year 1983		Fiscal Year 1984	
	Number of Awards	Amount	Number of Awards	Amount
Elec., Comp., & Sys. Eng.	489	\$ 29.53	515	\$ 35.46
Chem. and Process Eng.	514	22.56	505	25.99
Civil and Envir. Eng.	449	30.49	507	33.10
Mechanical Eng. & Applied Mech.	304	19.43	325	23.81
Subtotal	1,756	\$102.01	1,852	\$118.36
Adjustment to Internat'l Awards	—	-.88*	—	—
Total	1,756	\$101.13	1,852	\$118.36

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.
SOURCE: Fiscal Years 1985 and 1986 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) and NSF accounting records.

both must be firmly linked in the Centers. They will provide cross-disciplinary research opportunities for faculty and students and fundamental knowledge that can help solve important national problems, while giving engineering graduates the diversity and quality of education needed by U.S. industry.

NSF programs cover a broad range of fields: electrical, computer, and systems engineering; chemical and processing engineering; civil and environmental engineering; mechanical engineering and

applied mechanics; and interdisciplinary research. Consider the following diverse research projects: fabricating submicron structures smaller than any ever made; controlling biological reactions through novel methods in chemical processes; predicting the flow and velocity of waste discharges in rivers and canals; and understanding the fluid dynamics of nonlinear motion and its effects on ships and offshore structures. The following sections describe such projects.

Electrical, Computer, and Systems Engineering

Advances in the electrical sciences have resulted in better information systems and important techniques for machine decision and control. Society has come to depend upon electronics for many forms of information processing, communication, and health care—and for new technologies in manufacturing, robotics, automated control of industrial processes, and many other machine-controlled activities. Progress in machine processing is due largely to smaller and more compact elements and computers with greater versatility and accuracy.

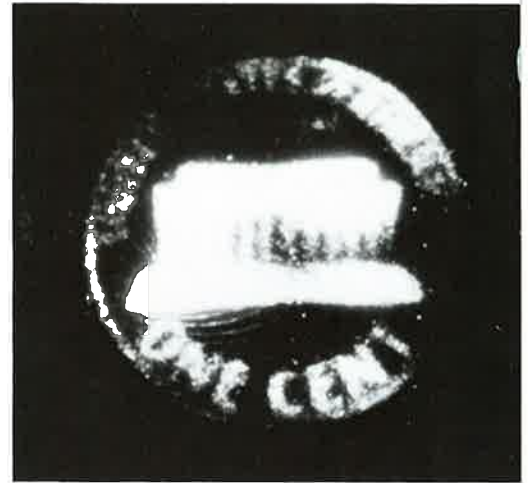
Capabilities in machine decision and control have evolved over the years—stimulated by advances in integrated circuits, very large scale integration (VLSI) technology, and much smaller components operating at ever higher speeds and processing more information per unit of time. Simultaneously, research has proceeded in cognitive science and artificial intelligence, “smart” sensors for visual and tactile sensing, automatic control algorithms, and improved system architectures. Along with these achievements, engineers have moved forward in system science and operations research. Mathematical approaches were introduced to make machine intelligence one aspect of a responsive, well-functioning system.

These same advances, plus progress in operations research methodology, point toward new techniques for applying machines to improve both economic productivity and use of our resources.

In electrical, computer, and systems engineering, research is not only interdisciplinary and multidisciplinary but also synergistic within the fields. Accordingly, progress in device research such as submicron electronics leads to new tools and building blocks in electronic systems; these find new applications that serve industry and improve the quality of our life.

Touch-Sensitive Robots

Today’s robots are complex electronic/mechanical devices that can be programmed to do a sequence of highly accurate and repetitious movements and manipulations. One characteristic of the next generation of robots will be their ability to sense any changes in their environment, as humans do through vision and touch, then control their motions accordingly. This ability would enable a robot to react instantly to an uncertain, unstructured, or changing environment. In addition, it would drastically reduce the programming effort needed to teach the robot new tasks and greatly cut the cost of



Tactile Sensor Imprint. At the Laboratory for Perceptual Robotics (University of Massachusetts, Amherst), researchers are developing new types of touch sensors for robots. Shown here is a tactile imprint of a penny, acquired by a sensor relying upon optical principles of operation. Tactile and vision sensors are expected to play a leading role in the next generation of robots that can actively sense their environments. Such robots will use that information to control their activities intelligently.

making the robot by eliminating the need for high-accuracy components.

Research on touch sensing by robots is under way at the Laboratory for Perceptual Robotics at the University of Massachusetts, Amherst. Under the direction of Michael A. Arbib, Kenneth Overton and Stefen Begej have developed touch sensors based upon several different technologies. Each sensor consists of an array of elements that sense force and displacement.

At 2.5 centimeters, Overton’s sensor is compact, dependable, and durable. Begej’s array measures 2.5 by 5 cm. and relies on the generation of an optical image. An important advantage of this approach is that it extends the range of tasks that a robot can perform.

Tactile sensors such as these are meant to give the robot information about the force and shape of objects while the robot manipulates, identifies, and assembles. The tactile aids would also augment visual sensors during periods of optical occlusion by the gripper or other objects in the robot’s environment.

The combination of visual and tactile sensing is an important advance in robot capabilities. Arbib's work is yet another step toward the goal of providing robots with the ability to emulate the human brain in intelligence and decision making.

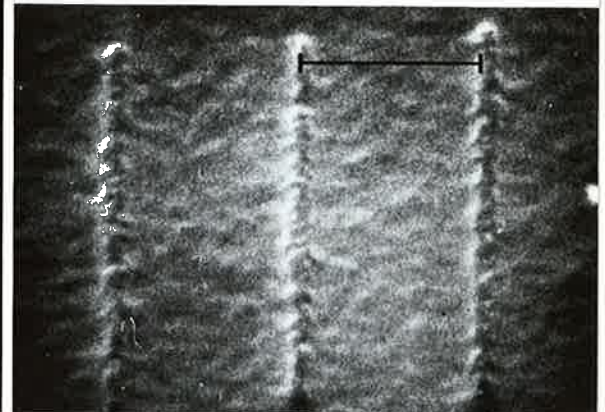
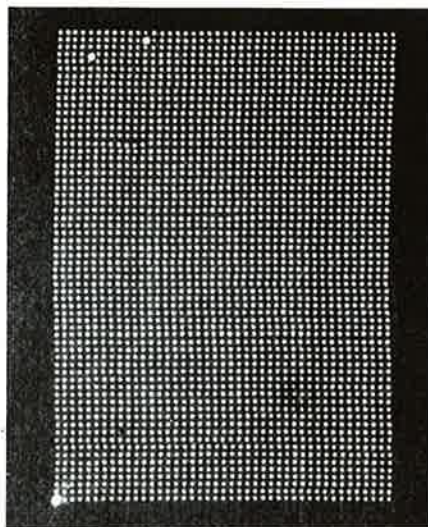
Other Work

- Lithography on a Molecular Scale**—The fabrication of nanometer-scale structures and the investigation of matter at dimensions previously inaccessible hold much promise for both basic science and applied technology. Potential applications of these advances include the study of light through apertures of less than one-millionth of a meter; work in metrology, the science of measurement; and a look at the dielectric properties of very small structures. In the past year Michael Isaacson and his research group at Cornell have used the Scanning Transmission Electron Microscope (STEM), at the National Research and Resource Facility for Submicron Structures, to develop techniques for fabricating such structures in thin-film and solid substrates. The team has, for example, fabricated thin-film masks with features smaller than 10 nanometers.
- Elements for Optical Computers**—Hyatt Gibbs and associates at the University of Arizona, in cooperation with Arthur Gossard and associates at Bell Laboratories, have demonstrated that optical logic can be created using a bistable optical

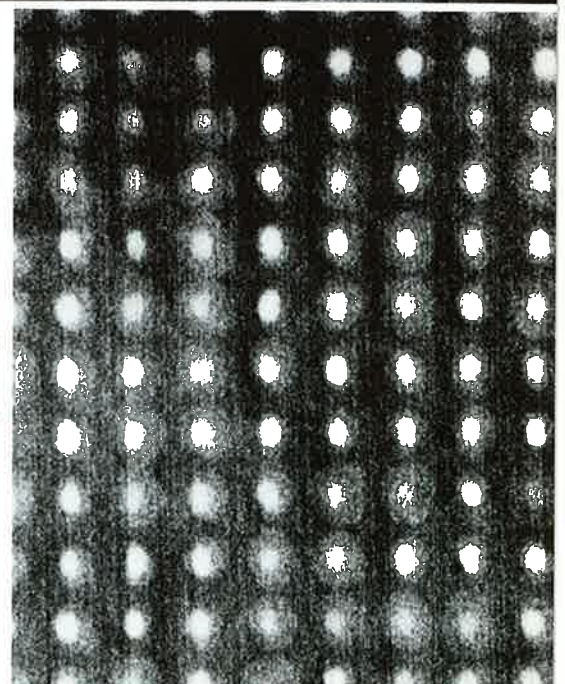
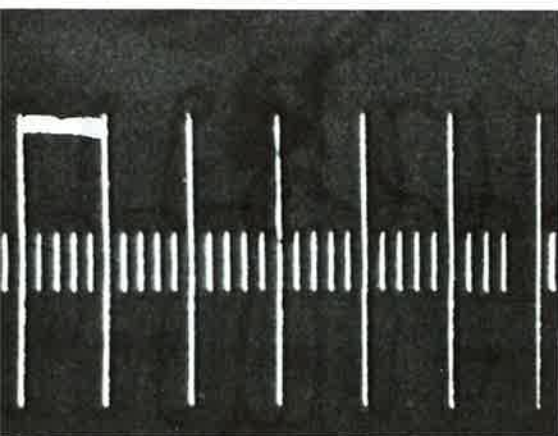
device. Gibbs was the recipient in January 1984 of the Albert A. Michelson Award, partially for his earlier contributions to optical bistability. This development could lead to optical computing techniques with much higher processing speeds than now exist.

- Large-Scale Systems Management**—Marshall Fisher of the University of Pennsylvania has been developing approximation procedures for solving problems that arise in such areas as vehicle routing and scheduling. These procedures, called Lagrangian relaxation, allow the solution of very large scale,

complex problems by relaxing the constraints to yield similar problems which can be solved in acceptable running times on modern computers. A number of industries have recognized the usefulness of these procedures and have applied them to their operations. For example, at Pennsylvania's Air Products and Chemicals, Inc., a system for inventory management of industrial gases at customer locations is integrated with vehicle scheduling and dispatching to yield significant savings in operating costs. So far this system has cut distribution costs by about \$1.7 million a year. DuPont's Clinical Systems Division figures it has saved more than \$200 million since it started using this system in 1980.



Fabrication of thin-film masks. These four figures show experimental fabrication of masks, using various resist and substrate materials on a submicron level. The first figure (at left) shows a thin-film mask with a calibration pattern superimposed on the film; the scale bar is 0.635 microns. The next illustration (above) depicts an array of holes on an 80-nanometer (nm)-thick film; the holes are 4 nm in diameter and spaced 8 nm between centers. A bright-field micrograph of a pattern of rectangular holes is seen in the third figure (at bottom right); the rectangles have dimensions of 8 by 10 nm. Finally we see a Scanning Transmission Electron Microscope (STEM) micrograph of a replicated mask; the scale is 500 nm.



Chemical and Process Engineering

The chemical process industries are a dominant force in the nation's economy, contributing about 8 percent of the gross national product. NSF is the only federal agency that supports research in all aspects of chemical processes, providing more than 90 percent of the federal funding to universities for this research.

Better understanding of the scientific principles and concepts that industry relies on has led to improved designs in key industries—among them petroleum/petrochemicals, foods, pharmaceuticals, minerals, pulp and paper, chemicals, and others. Another area likely to benefit from research in chemical and process engineering is biotechnology. The emergence of technology associated with recombinant DNA and its potential applications has created a need for new engineering knowledge. Vital biochemical engineering research areas include reactor design with recombinant organisms and product separation and purification.

The Foundation works to strengthen colleges and universities through Presidential Young Investigator Awards to new graduates; through industry-university cooperative research programs that pool the resources, ideas, and capital of industry and academe; and through growing support of basic research equipment, the so-called "infrastructure" of science and engineering. Following are examples of work aided by NSF last year.

Fluidized Beds: Tracking Particles by Computer

A fluidized bed reactor is a vertical cylinder containing small solids suspended (i.e., "fluidized") by a rising stream of fluid, usually in the form of gas, so that the fluid and solids come into very close contact in a turbulent way. This technique results in better and faster chemical processes.

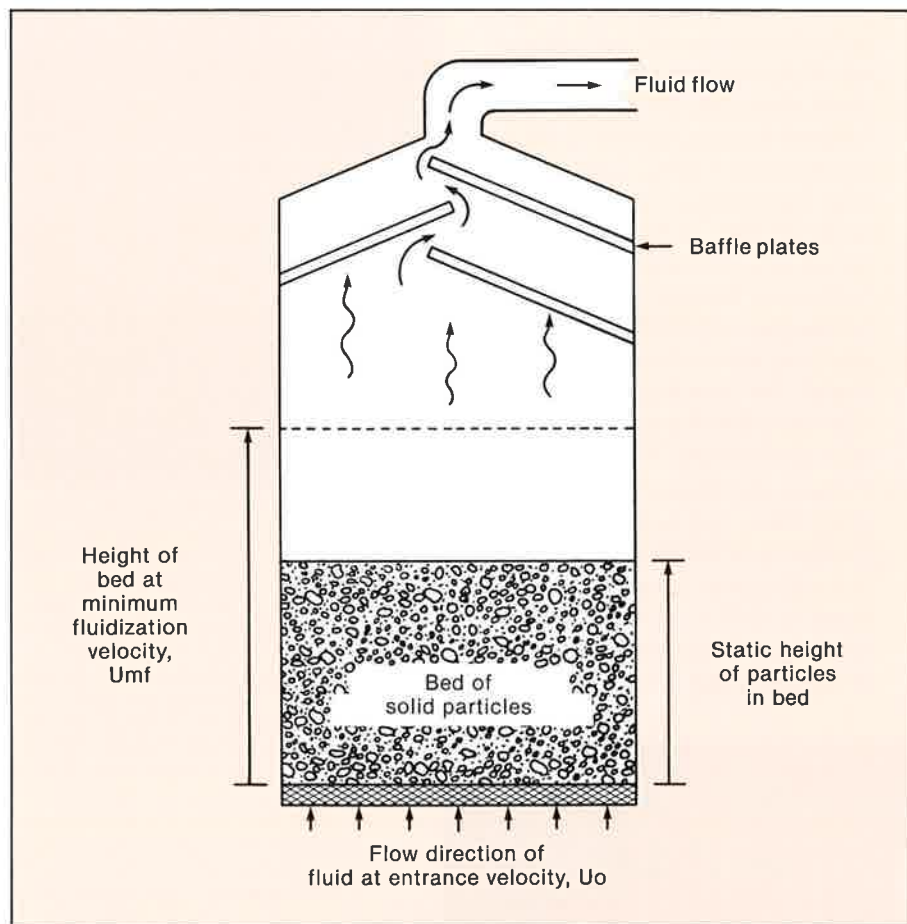
In industrial settings, fluidized beds may range in diameter from centimeters to more than 12 meters and may reach well over 15 meters in height. The devices are particularly advantageous for processes that require thorough mixing, intense heat, and mass transfer, or for catalytic reactions that need close contact between solids and liquids or gases.

Fluidized bed reactors increase processing rates and efficiencies while operating at low pollution levels. The relative simplicity of their construction, their superior mixing of reactants, and their abil-

ity to maintain uniform temperature in the presence of nonuniform heat release all underline their suitability for chemical processes in industry.

Despite its importance to many commercial processes, the design of a fluidized bed system is difficult, imprecise, and based mainly on previous experience. Knowledge of the basic phenomena surrounding these beds is still rudimentary—especially knowledge of flow behavior, which is needed to determine the most economical size of a bed and to establish its most efficient operating conditions. Without this fundamental knowledge, the design of a fluidized bed process can be costly and complicated.

Bates Chao and his coworkers at the University of Illinois, Urbana, have ob-



Simple Fluidized Bed. Schematic shows the bed as a vertical column of small solids suspended, or "fluidized," which brings them into close contact with gases or liquids. The fluidized bed reactor offers a number of advantages over other methods of producing this contact — for example, high rates of heat transfer, uniform temperature, and mobility of the solids. Fluidization is now a major technique to increase processing rates and efficiencies while operating at low pollution levels.

tained circulation patterns of solid particles flowing in a fluidized bed—a key advance in the technology. Earlier quantitative measurements of a particle's motion and velocity in dense suspensions have been scarce because of the opacity of such suspensions and the interference of immersed sensors with the actual motion. The Computer-Aided Particle Tracking Facility at the University of Illinois bypasses these problems and offers great potential in this research area.

Commercial Uses of Fluidized Beds

Power plants (combustion)
Waste incineration and heat recovery
Pyrometallurgy
Coal gasification
Food processing
Pharmaceutical processing
Shale and tar processing
Catalytic cracking of petroleum
Polymerizing of plastics

The facility employs a radioactive test particle, identical in density, size, and shape to typical solid particles in the bed. As it moves about in the bed, its radiation is monitored by up to 16 detectors located outside the bed. The output of the detectors is fed to an online minicomputer, which is able to track the position, velocity, and direction of the radioactive tracer. After many thousands of measurements, average velocities are obtained for all locations in a fluidized bed. This is the first quantitative evidence of the complex recirculation patterns in a fluidized bed.

The Computer-Aided Particle Tracking Facility can help engineers determine the circulation patterns of solids in a fluidized bed affected by such factors as inlet velocity, size and distribution of particles, internal conditions, and the location of feed and withdrawal points. Basic engineering research continues to formulate the fundamental equations involved in these processes. The circulation patterns, particle velocities, and velocity fluctuations determined by this tracking facility are crucial experimental input.

Controls for Biological Reactors

In biological reactors (bioreactors), control of process conditions is necessary to maintain the feasibility of process operation and to create the best product distribution. Two examples are the need to control fermentation in certain types of ethanol production and single-cell protein production. These and other fermentations have been known to oscillate, and in a production environment such oscillations are generally undesirable. Attempts to stabilize them using conventional controllers have been unsuccessful.

In ethanol or amino acid fermentations, increases in productivity on the order of 50 to 100 percent can be realized by controlling the oxygen concentration at appropriate levels. Removal of foreign protein (artificially introduced DNA) in recombinant microorganisms can be improved as much as 100 percent by controlling environmental conditions. Moreover, with proper control techniques scientists can detect early signs of contamination or mutation in cultures, which accounts for loss of 25 to 30 percent of all batch fermentations. Early detection of these unusable cultures minimizes the waste of costly nutrients and saves process time.

Careful examination of fermentation systems and the basic characteristics of potential control structures suggests that effective controls must (1) determine, online, the state of a bioreactor, and (2) predict the response of a biological system to imposed changes in culture environment.

Gregory Stephanopolos at the California Institute of Technology has investigated the problem of online bioreactor identification. His work has resulted in a methodology that can give accurate and noise-free estimates of key bioreactor variables. It also has permitted the determination of hard-to-measure quantities such as specific growth rates for product formation. The methodology is unique in its ability to produce very good estimates under both steady-state and transient conditions.

The development of online fermentor monitoring and predictive capabilities for a microbial system is essential for fermentor control and useful for microbial kinetic studies in general. Research in this area should produce basic results both in the biochemistry of microorganisms and in the development of novel approaches for controlling complex microbiological systems.

A New Way to Get Cancer Information

In a striking example of the growing interaction between engineering and medicine, a chemical engineer has developed a unique way to quantify how blood and various drugs circulate and behave in tumors. This information is critical to some methods of cancer detection and treatment.

Rakesh K. Jain of Carnegie-Mellon University headed the team responsible for this development. He calls the new method "unique in cancer research" because it allows one to observe directly for the first time how the flow of blood, the transfer of matter in the blood stream, and the growth of tumors are affected by drugs and heat in a living organism.

Jain and his associates developed a tiny glass chamber that enables them to monitor continuously both normal and tumor tissues as they grow in a rabbit's ear. The chamber is formed by placing glass plates on the inside and outside of a hole in the ear, leaving a hollow space in the middle. The chamber makes it possible to observe cancer cells as they produce chemical agents that signal nearby blood vessels to grow toward them.

As the tumor in the rabbit's ear grows and develops its blood supply system, it can be observed microscopically through the transparent window. The temperature of the tissue is controlled by a tiny heater mounted on the chamber.

Understanding the role of blood flow in tumors is important in radiotherapy (radiation treatment), chemotherapy (the use of drugs), and hyperthermia (the application of heat), three widely used methods for treating cancer.

Civil and Environmental Engineering

In 1984, NSF emphasized a new program dealing with construction engineering and building research—two areas in which considerable study and work are needed to improve the nation's structures. Before starting this program, the Foundation did extensive studies throughout the country to identify the construction problems amenable to attention by university researchers. Concurrently, NSF also considered the traditional challenges of civil engineering, where three fields were identified as having been relatively neglected—transportation engineering, coastal and ocean engineering, and construction materials.

An issue involving many civil engineers today is increasing concern with the nation's physical infrastructure—such community facilities as roads, bridges, water and sewage systems, ports and rivers, even buildings of various types. In recent years, public expenditures for these facilities have declined, resulting inevitably in the deterioration of the infrastructure. Studies of this widespread problem have reached an unvarying conclusion that the situation must be addressed and improved.

The public infrastructure can be improved by a number of means. The conventional procedure is to build new facilities, and this will probably continue to be the main way of meeting the need. Still, many parts of the infrastructure can be preserved and facilities already in service can be upgraded by repair, retrofit, and rehabilitation. This approach to the problem requires more research attention.

Base Isolation to Resist Earthquakes

Base-isolation research is a central topic in the earthquake engineering community. Traditional methods of aseismic design rely on the strength and ductility of a building's structural elements. In base isolation, the entire structure is isolated from the horizontal seismic motions

that tend to make structures vulnerable to severe earthquakes. Knowledge and understanding of horizontal ground forces are important in designing buildings, bridges, and other facilities in highly seismic areas. Vertical forces, by contrast, are usually accommodated by normal design practices.

The long-term response to earthquakes requires research to develop good structural design methods, a community of trained earthquake engineers, and a body of knowledge and experience in earthquake engineering. As part of this, various base-isolation schemes and configurations are being investigated. In the elastomeric pad, for instance, the structure is founded on flexible pads to reduce considerably the forces transmitted to the structure. Variations on this scheme include reinforcing the elastomeric pad with steel plates, inserting a lead plug to increase damping, and allowing relative displacement between the isolation pads and the structure. Two other base-isolation techniques under study consist of supporting structures on ball bearings and using multiple friction surfaces. With base-isolation systems, structures can resist minor earthquakes without damage and major earthquakes without collapsing.

Other types of controls and energy-absorption devices also are under study. These include active control of a structure during an earthquake, by imparting motion to offset quake motions. Viscous and frictional elements are being considered as passive control devices to dissipate the energy from an earthquake.

The application of base isolation to actual structures is best illustrated by the new Law and Justice Center Building in San Bernardino County, California, which uses a reinforced elastomeric-bearing system as part of its aseismic design. Supported by NSF for several years, research leading to this application has been performed by James Kelly at the University of California, Berkeley, and others.

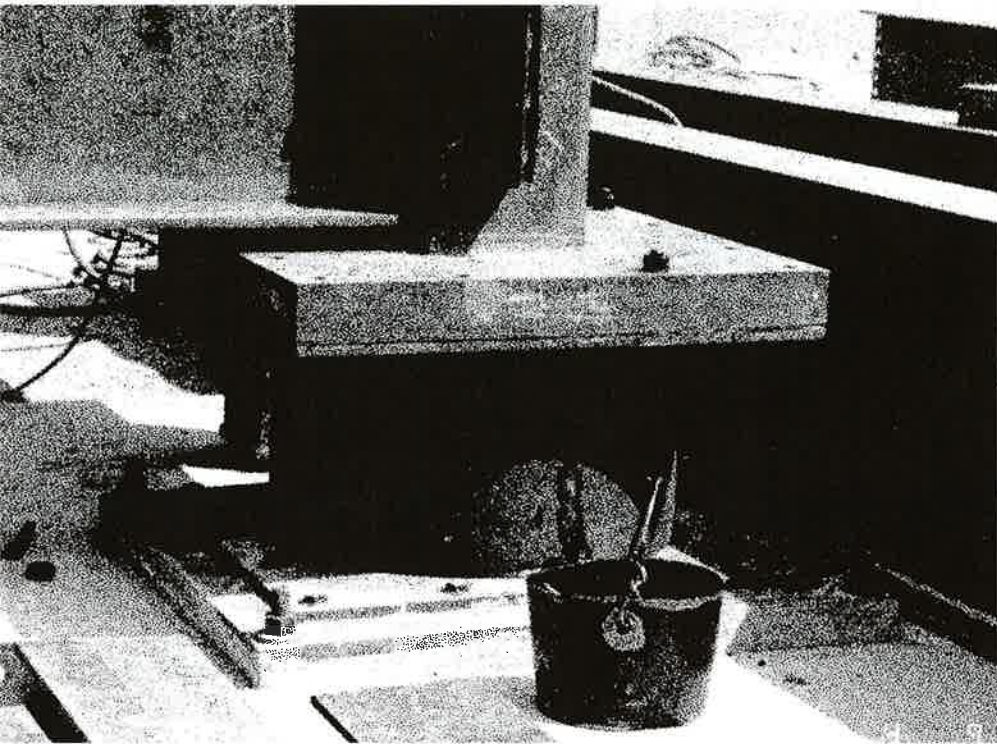
There is now a growing interest in base isolation among engineers, developers, and building owners. For example, N. R. Vaidya and A. J. Eggenberger of D'Appolonia Engineers have studied the technique's feasibility in designing various structures. They examined three schemes of the reinforced elastomeric-bearing type and concluded that the concept is sound and technically feasible for protecting structures from ground motions.

In one case study of a hospital, the researchers found that an isolation system could be designed and installed at no extra cost. Their research also concluded that the base-isolation concept is feasible for structures that are relatively rigid, and it can be incorporated at equal or lower cost than conventional designs. This is especially true for buildings (such as hospitals) that traditionally incorporate more safety features because they must continue to operate during and after a major seismic event, and for structures with equipment and systems which are particularly sensitive to earthquake-type motion.

In another experimental research program, UC's James Kelly studied the performance of base-isolated bridge decks under earthquake loading. He found considerable reductions in the horizontal forces transmitted to the bridge structure. Kelly's research will be useful in preparing design guidelines for isolators and energy dissipators.

I. G. Tadjbakhsh at Rensselaer Polytechnic Institute also has examined the behavior of base-isolation and energy-absorbing systems. His theoretical research has produced concepts for optimum use of these systems under various seismic conditions.

Both analytical and experimental research on base-isolation systems shows that it is possible to predict structural response as well as reduce the earthquake motions transmitted to a structure and its contents. More research is continuing in response analysis, the effects of aging and environment on material properties, and full-scale experimentation.



Base-Isolation Pad. This pad isolates a building from horizontal ground motion that occurs during an earthquake. Reinforced with steel plates, the elastomeric pad significantly reduces the forces transmitted to the building. This system has been installed in the new Law and Justice Center in San Bernardino County, California.

Sediment Transport in Alluvial Streams

A research program on sediment transport and flow in such alluvial channels as rivers and certain canals has been supported for the past few years by NSF at the Keck Laboratory of the California Institute of Technology. During the program, directed by Norman H. Brooks, several graduate students earned doctoral degrees. One dissertation, "Flow Depth in Sand-Bed Channels," by William R. Brownlie, received the 1984 Alfred Noble Prize from the American Society of Civil Engineers.

This research project addressed the long-standing civil engineering problem of predicting the velocity and depth of flow for a given discharge in a river or unlined canal. In such bodies of water, the shape of the channel determines that velocity and flow depth and in turn can be changed by them.

A numerical model requires a logical scheme, which engineers use to predict

velocity and other information for a channel of given dimensions, bed material, bed slope, discharge, and water temperature. For certain ranges of these parameters, multiple values of sediment discharge and flow depth may be possible. However, the engineer is often faced with the problem of designing a channel to accommodate a given discharge with a given bed slope and an unknown sediment discharge.

The Caltech project addressed the situation where sediment discharge was assumed to be unknown. The researchers explored possible solutions for uniform flow depth as a function of discharge, bed slope, and bed-sediment and fluid properties. They sought a technique for calculating directly the uniform or normal flow depth of a channel with a given discharge. Using the technique, an engineer could apply a numerical model for unsteady, nonuniform flows. Such a technique would need to (1) agree with laboratory and field experience, (2) include confidence limits or some statis-

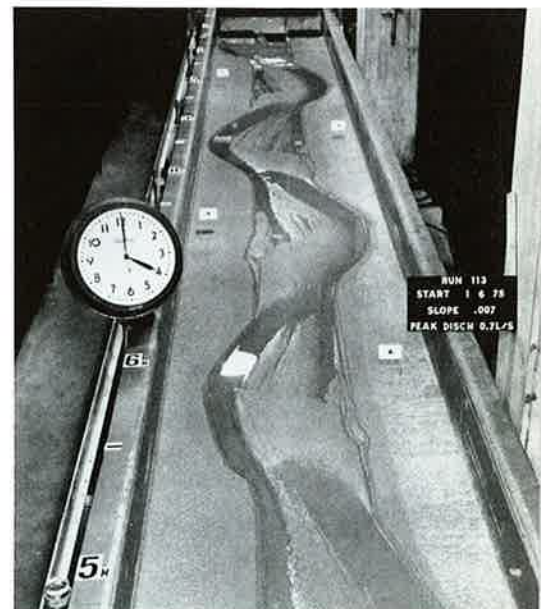
tical analysis of the input data to indicate expected errors, (3) be easily adaptable to computer modeling applications that may require thousands or even millions of flow-depth calculations, and (4) provide solutions for a wide range of independent variables.

The researchers examined six existing methods for predicting the "friction factor," which is essential in computing velocity and flow depth. None of the six approaches completely satisfied the criteria listed above, so they came up with a new analytical method that does.

The new technique is based on dimensional analysis, statistical analysis of a large body of laboratory and field data, and basic principles of hydraulics. It was verified through comparisons with data sets not used in deriving this approach.

This work provides methods for designing unlined channels to transport sediment-laden water. With those methods, there is a much higher probability that the channel will be stable and continue to convey the required quantities of that water over much longer periods of time.

Lab measurements of sediment discharge and flow. Researchers use small-scale physical models of unlined earth channels, such as rivers or irrigation canals, to understand what makes meandering take place. Meandering can decrease the amount of water an irrigation canal can carry or make a river change its channel, causing flooding, destruction of property, and loss of life. (Photo from *Journal of Fluid Mechanics*, vol. 76, part 3)





Field measurements of sediment transport. These measurements in Pakistan's Link Canals verify laboratory research results. They are part of a cooperative research project with Khalid Mahmood, at George Washington University, and researchers at the Water and Power Development Authority in Pakistan.

Mechanical Engineering and Applied Mechanics

Fundamental research in this area is vital to U.S. industry. Manufacturing high-quality products to compete in world markets depends in part on our ability to:

- Control the efficient conversion/consumption of energy.
- Predict the complex motion of fluids.
- Determine precisely the strain and stress conditions in high-performance components.
- Control the behavior of automated machinery and robots.
- Devise and integrate new production processes into computer-aided manufacturing systems.

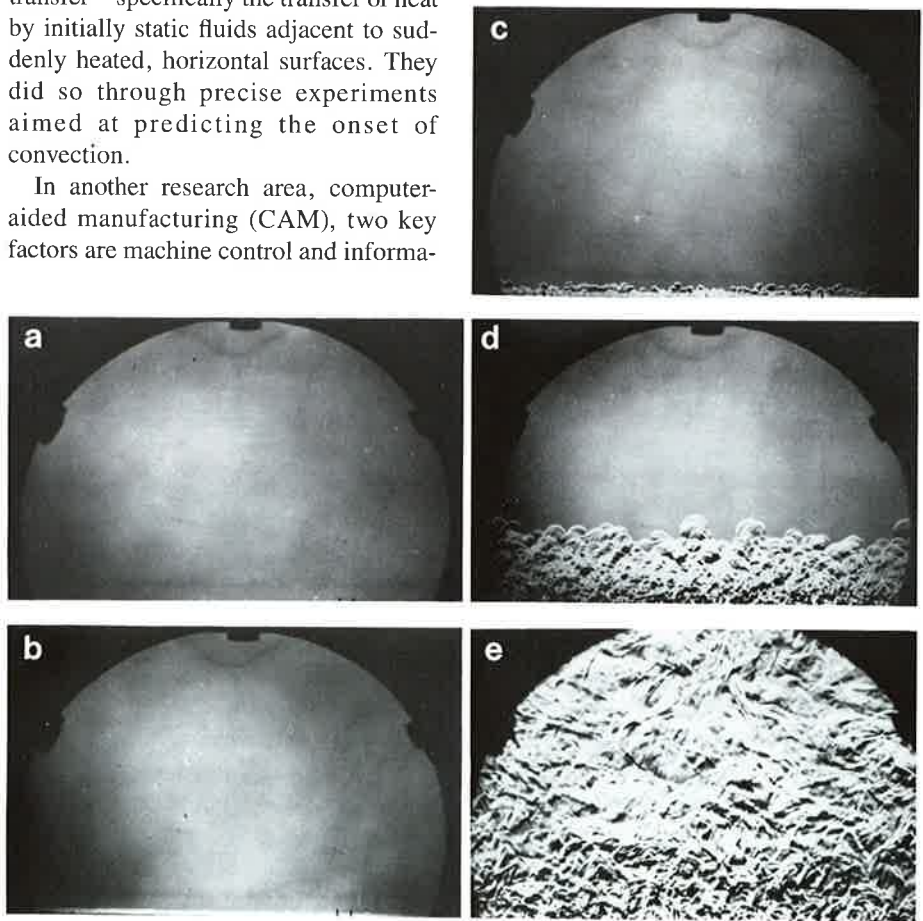
Heat Transfer. Researchers at the State University of New York at Buffalo have experimented on ways to predict the onset of convection by static fluids adjacent to suddenly heated horizontal surfaces. This sequence of photographs shows the growth of an initially stagnant conduction layer (a) and (b), then the appearance of laminar plumes (c). These ultimately neck down (d) due to perturbations that propagate down to the heated surface, reducing its temperature while leading to the formation of meandering wispy columns (e). This work leads to better understanding of the atmospheric motions caused by sudden heating of the earth's surface by solar or other types of radiation. It also aids the design of certain kinds of heat-transfer equipment in process industries and power plants.

In NSF-supported work last year, J. C. Mollendorf and his associates at the State University of New York at Buffalo added new knowledge to the key area of heat transfer—specifically the transfer of heat by initially static fluids adjacent to suddenly heated, horizontal surfaces. They did so through precise experiments aimed at predicting the onset of convection.

In another research area, computer-aided manufacturing (CAM), two key factors are machine control and informa-

tion control. R. G. Askin at the University of Iowa studied the use of an interactive simulator with a numerically controlled, turret punch press; he has developed an algorithm to minimize cycle time on this device. At Cornell, J. A. Mackstadt, W. L. Maxwell, and L. J. Thomas have studied information-control models for planning and directing multistage systems to manufacture discrete parts. This grant's three phases include preparing a long-range master production plan, providing for unforeseen work stoppages or supply shortages, and setting up short-range production schedules.

Ward Winer at the Georgia Institute of Technology has done research on how friction hotspots adversely affect the wear and load capacity of tribocontacts (friction points). Such problems often create limitations in the design and development of mechanical systems. For



example, in developing adiabatic diesels (those in which heat is neither gained nor lost), good triboelement performance at high temperatures has not been achieved at this writing.

The Georgia Tech project has included (1) the experimental study of surface hotspot dynamics in sliding tribosystems, along with analytical modeling of the hotspot, and (2) the generalized thermal modeling of tribosystems, including development of appropriate computer software. The thermal measurements have been made with an existing tribology research system at Georgia Tech, augmented by a scanning infrared camera acquired through this NSF grant. The research is expected to yield better understanding of thermal phenomena in tribosystems.

Other work is described below.

Nonlinear Problems in Fluid Mechanics

In the past 30 years, linear analysis of ships buffeted by waves has become one of the best studied and most useful branches of ship engineering. Experiments suggest that linear predictions of ship motions, structural loads, and related phenomena are accurate enough for most engineering purposes. The parallel field of offshore engineering also has made extensive use of linear theory to predict the effects of waves on a wide variety of structures, such as oil-drilling rigs.

Despite the success of linear theory, practical engineering problems remain where nonlinear effects are paramount—for example, in the seaworthiness of ships and offshore structures. Since survival and safe operations are primary concerns here, a note of urgency attends efforts to overcome the linear restriction in the theory of ship motions.

At the Massachusetts Institute of Technology, J. N. Newman, D. K. Yue, and graduate student W. M. Lin have investigated the nonlinear forced motion of floating bodies. Their work was motivated in part by the 1979 Fastnet Race disaster, in which dozens of small sail-

boats capsized and sank in minutes during a sudden storm off Great Britain's coast. The boats upset by steeply breaking waves were not designed to withstand the hydrodynamics of the sea that day.

Other reasons for this research: extreme yawing in some fishing vessels, structural collapse of ships slammed by waves, and loss of major offshore structures in severe storms. All of these situations require the ability to analyze the seaworthiness of floating bodies when their motions (and the amplitudes of nearby waves) are comparable to their body dimensions.



Fluid Mechanics. Researchers at the Massachusetts Institute of Technology, seeking to predict the seaworthiness of vessels and offshore structures in sudden storms, performed an experiment illustrated in this photograph. It shows the formation of a jet at the free surface of a liquid being accelerated by the impulsively moved plank on the left. The experiment was compared with computed time-sequence behavior of the free surface under similar conditions.

The MIT group has done a set of simplified experiments coupled to large-scale computational analysis on a Cray-1S computer made available by the Foundation. The group used a two-dimensional model in which the water surface undergoes significant displacement. In this case linear theory is not applicable. Therefore, special attention went to the intersection point of the free

surface and the moving body, where boundary conditions cause mathematical problems (called singularities) in linear theory. These singularities are avoided in the real fluid by the formation of jets, which quickly break up into spray under surface tension.

The group has derived a local solution, valid for the intersection point and based on potential flow theory. They also have gotten numerical results for both accelerating and decelerating bodies; their predictions had not been reported before. Moreover, comparison between an actual experiment and a computer prediction during the acceleration phase showed remarkable agreement. Newman and his colleagues are continuing their research on a variety of nonlinear water problems. Their work is an important step toward preventing open-water disasters.

Precision Measurements: New Advances

NSF-funded research in solid mechanics has produced significant technological benefits through improvements in precision measurement. For example, Fu-pen Chiang at the State University of New York, Stony Brook, has developed a method for quantitative measurement using a random pattern on an object.

The random pattern can be generated easily. In some cases it may already be a natural part of surface texture, as in sprayed paint particles, scratches, or the natural grain structure. A simple way to generate the random pattern is to illuminate the surface with a laser beam, which results in a pattern known as a "laser speckle." This speckle can be used to measure (1) the response of materials subjected to force, vibration, fatigue, or impact, and (2) the velocity and temperature distribution in fluids.

The SUNY technique has wide application. A dental scientist has used it to measure the smoothness of teeth and dentures, while the U.S. Army's Ballistics Research Laboratory at Aberdeen, Maryland has adopted the technique to measure the oscillation of a gun barrel during firing.

The method should be especially useful in the fields of materials science and engineering. By depositing particles so small that they can be observed only through an electron microscope, investigators can measure the microscopic deformation between or within the fine grains of materials.

In a different advance in precision measurement, Daniel Post at the Virginia Polytechnic Institute and State University has developed an important tool in the design of turbine engines. Using an optical technique called moire interferometry (in which a rectangular grid of lines is scribed or replicated on a surface), he came up with a method to produce a density of lines—24,000 lines per centimeter—far greater than had previously been possible.

In collaboration with Carlos Ruiz at Oxford University, England, Post has applied this technique in measuring the microscopic sliding motion between the root of a turbine blade and the rotating

disk to which the blade is attached. The minute motion occurs as the blade-root fixture is subjected to great mechanical stresses from the high rotational speed of the turbine, as well as the tangential forces associated with the generation of power. All of this results in friction, wear, and ultimately fatigue failure.

Such events at the blade root had not been well understood; as a result, it has been standard practice to remove the turbine disk frequently—often prematurely—for inspection. This is a costly procedure, but one deemed necessary to guard against catastrophic failure in turbines powering commercial and military aircraft, plus a variety of stationary and mobile equipment.

The technique developed by Post and Ruiz will give the designers better understanding of events occurring at the blade root, thus enabling more efficient design and more accurate prediction of the fatigue period. This could lead to better engine life and lower operating costs.

Lightwave Technology

The invention of the laser a quarter-century ago is a compelling example of the interchange between science and technology. Quite apart from the fundamental new physics intrinsic in lasers, applications and implications of the devices have been remarkably pervasive throughout science and engineering—and in areas as disparate as medicine and the fine arts. Lasers also have led to the exciting new fields of nonlinear optics and lightwave technology.

The laser gives us the means to generate light that can be both highly coherent and extremely powerful. As techniques to transmit and manipulate this light developed, so did applications and potentials. Lasers are used for welding, drilling, and cutting; for precisely measuring distances on the surface of the earth and between the earth and moon; and for various military purposes, both passive (as in range finding) and active (as in antimissile defense).

Other applications combine lasers with information to form such new technologies as optical communications, information processing, and sensing—plus the subfield of optics and electronics. Optical communications is a clear example of the commercial success of lightwave technology—shown most remarkably by the development of an optical fiber communications cable on the floor of the Atlantic Ocean.

On the horizon and showing great commercial potential are optical fiber sensors for both commercial and military applications—for example, to detect rotation, acoustic waves, and magnetic fields. Other sensing applications include holography for quality assurance and robot vision. Finally, remote chemical sensing, made possible by the invention of the laser, is important in pollution detection and in the chemical processing industry.

There is tremendous growth potential in optical signal processing. With a long history originating in holography, such processing is showing a resurgence in the 1980s. Acousto-optics and integrated

Interdisciplinary Research

NSF's Office of Interdisciplinary Research spurs and organizes research involving more than one scientific or engineering discipline, and works with other Foundation staff to encourage such activities. One of the Office's most important new programs is a group of cross-disciplinary research centers on university campuses. These Engineering Research Centers would strengthen engineering research and education and improve academic ties with the nation's industrial community.

Although no single model has been chosen for the centers, each will concentrate on fundamental engineering research and formulate a program based on the "systems approach" to engineering. A key to each center's program will be the involvement of students and faculty with industry.

The ongoing responsibilities of the Office of Interdisciplinary Research (OIR) include funding workshops and state-of-the-art review papers that (1) identify research needs, (2) develop cross-disciplinary collaboration, and (3) point to new NSF program possibilities in this area. The Office also brings together diverse NSF programs, which jointly fund and develop a wide range of topical subjects. Among these: Biotechnology, Robotics and Automated Manufacturing, Science and Technology to Aid the Handicapped, Soils and Soil Science. Finally, OIR supports research to develop instruments that will advance rising interdisciplinary fields.

Following are examples of workshops that highlighted research needs in two emerging areas last year.

optics have demonstrated that real-time, radio-frequency spectrum analyzers have both military and commercial uses. The future of such fields as robot vision may depend upon progress in optical signal processing.

In combination, optics and electronics make up a new field, still primarily in the research stage but suggesting great promise for many future applications. The control of electronic devices with light is increasingly important. A related role is the capacity of light to communicate information from the plane of a semiconductor chip for the next generation of computers. To increase the speed of computations, both inter- and intrachip communications in electronic processors will be done by lightwave technology.

The power of light to interact with other media, causing temporary or permanent changes, is central to other important uses of lasers and lightwave technology. Of special note is the successful use of lasers in surgery (for example, in repairing detached retinas), dentistry (as a possible replacement for the dental drill), and other medical treatments.

In addition, lasers have varied roles in processing industries:

- Laser heat treating and machining have been routinely used in heavy manufacturing.
- The use of lasers in hardening surface materials without warping them is very important to the automotive and hard-goods industries.
- Laser welding plays a crucial role in aircraft engine and other production.
- The laser's ability to focus tightly and selectively deposit, etch, or cut has been put to good use in the microelectronics industry.

In recognition of these developments, NSF aided a workshop on "The Future of Lightwave Technology." Organized by Michael Bass and Elsa Garmire at the University of Southern California, this gathering took place in January 1984. Its findings are shown in the two tables accompanying this text.

(*Ed. Note:* See also "Masers and Lasers" in chapter 2 of this report, under Social and Economic Sciences.)

Sensors for Biotechnology

The dramatic advances in biotechnology over the past 10 years reveal the need for new measurement and sensing systems. To commercialize biotechnology still further, such systems should combine sophisticated measurements of chemical and biological media and integrate those with computerized interactive control systems.

In many areas biotechnology has expanded to the point where traditional measurement technologies such as chromatography cannot give us the real-time control information needed in large-scale production. For example, there are urgent requirements for microsensor systems that can provide real-time monitoring on biological feedstocks (e.g., glucose amino acids) and on the metabolic products of the cultures scientists use. Measurement of other variables such as temperature and pressure will be crucial in developing continuous feedback control systems, which could replace current processing methods.

New options for biotechnology have appeared with the advent of microfabricated sensors based on the photolithographic techniques of solid-state electronics. Now there is a call for low-cost, high-reliability sensors. Problems posed by the need to understand the exquisite selectivity of biological systems, while no closer to resolution, offer unique opportunities for research in sensor development by several disciplines.

General-purpose sensors, capable of sensing a variety of target molecules selectively and specifically, are required for a wide range of uses. Especially promising are thermally based sensors and fluorescences. Advanced data-reduction techniques are also needed to provide specific responses, via pattern recognition, from arrays of imperfectly selective sensors. Major research contributions can be expected in such topics as:

1. Macromolecular properties of biomolecules pertinent to sensing.
2. Nonlinear behavior and noise in biological systems in excitable membranes.

Major Research Areas for the Future (as listed by Lightwave Technology Workshop)

1. New lasers operating at new wavelengths.
2. Generation and use of ultrashort pulses.
3. Interactions of light with matter.
4. Optical information processing and communications.
5. Spectroscopy and laser-induced chemistry.
6. Nonlinear optics.
7. Laser materials processing.
8. Fiber and integrated optics sensors.

Workshop Conclusions

- Much of the future research needs to be interdisciplinary. In each of the application areas listed above, as in all aspects of research required for laser development, collaboration between physicists, chemists, electrical and chemical engineers, and materials scientists needs to be stimulated.
- The potential of lightwave technology is enormous. Already a rapidly expanding high-technology field, it is also an expensive research area. Lasers, high-speed electronics, precision optical hardware, and instruments are all expensive and must be constantly upgraded. Students need training to operate such equipment, and teaching laboratories must be well funded to enable growth in lightwave technology.
- Fields of study that are peripheral to lightwave technology also must be adequately supported. A limiting factor in lightwave research and engineering is the fact that materials for laser hosts, infrared and ultraviolet optics, specialty fiber optics, thin films, and nonlinear optics are not readily available.

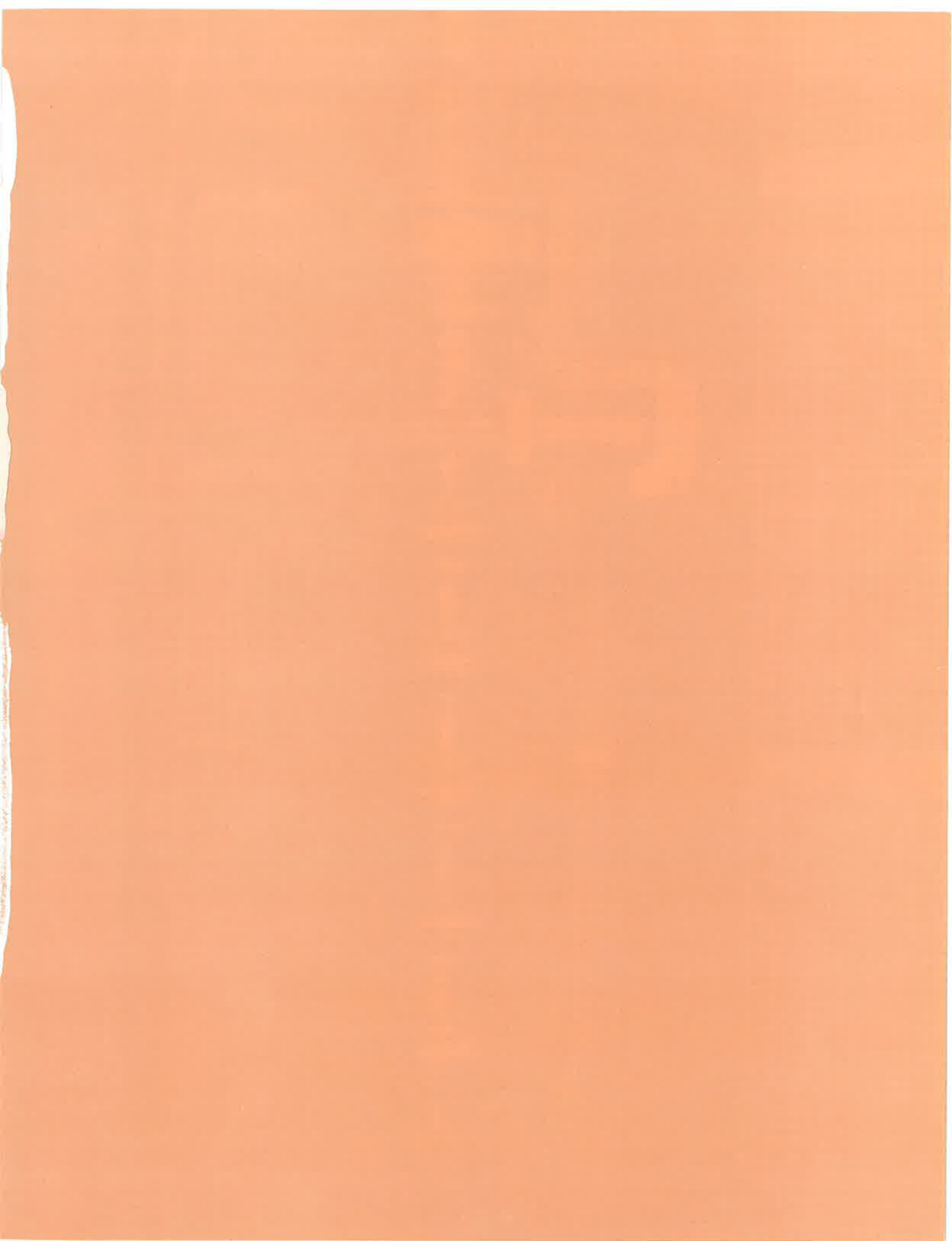
3. Special materials and fabrication techniques needed for chemical, thermal, pressure, and other sensitivities.
4. Immobilization techniques for membrane interfaces.
5. Ion transport and membrane technologies.

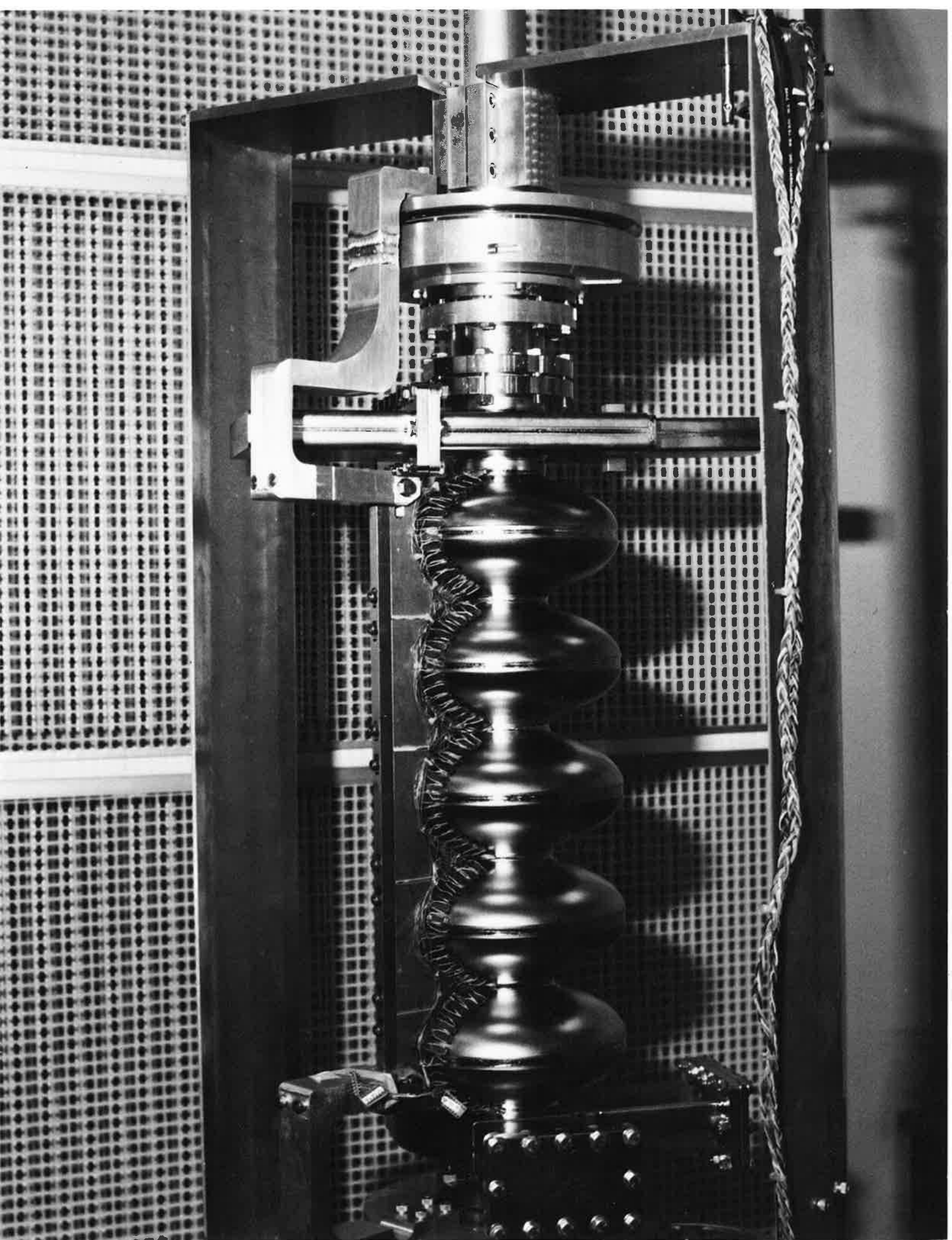
With NSF support, a workshop on Biotechnology and Microsensor Information Acquisitions Systems was organized by Jay N. Zemel, University of

Pennsylvania, and held in November 1983. During the workshop, there was a clear message that further advances in microsensor systems for biotechnology will have to come from a diversity of technical and scientific disciplines. These include electrical engineering, chemical engineering, biology, and chemistry. As an illustration, the type of microfabrication technology that has evolved in developing very large integrated circuits is fundamental to microsensor research. Even so, this tech-

nology is only one aspect of microsensor research and, to develop the subject properly, the sensor scientist needs the expertise of a physical chemist.

Formidable barriers to further advancement in this field are the differences in language and methodological perspectives among electrical engineers, chemists, and biologists. The workshop recommended support of larger, multidisciplinary teams aimed at bridging the differences between disciplines.





Mathematical and Physical Sciences



To ensure the health and vigor of these disciplines, NSF sponsors work in the mathematical sciences, computer research, physics, chemistry, and materials research. The goal of these investigations is to increase our understanding of the universe around us and the world in which we live. Projects in the mathematical and physical sciences promote and advance scientific progress and technological development. Such projects help to:

- Create new mathematical knowledge and apply it to a fuller comprehension of natural phenomena.
- Develop an understanding of the science that underlies computational processes; formulate basic principles to design novel applications and new, more powerful computing and information-handling systems.
- Advance knowledge of the fundamental laws governing the basic properties and interactions of matter and energy—with the ultimate goal of achieving a unified, self-consistent explanation of all physical phenomena.
- Stimulate progress in modern chemistry on a broad front—including chemical analysis and chemical synthesis, which are central to technological advancement.
- Improve understanding of the composition and structure of materials and interactions between their constituents.

The results of these efforts form much of the foundation for research in the bio-

logical, medical, environmental, social, and behavioral sciences, and in engineering. They are also the source of much of the research instrumentation and methodology required for advances in these research fields.

A recent characteristic of research in all sciences has been the convergence of investigations within different disciplines on problems that transcend their boundaries. Consonantly, research in the mathematical and physical sciences is increasingly characterized by its strongly interactive nature. This is evident, for example, in the mathematical sciences, where researchers in various subfields address and solve problems from other areas of mathematics and science. Similarly, materials research is a highly multidisciplinary field with many complex

connections and roots in physics, chemistry, and engineering.

There are also significant links across the disciplines: between atomic and molecular physics and chemical physics; between chemistry and materials research; and, in the area of computational mathematics, between mathematical sciences, computer research, and many fields of science and technology. These interactions are strengthened by common use of rapidly developing methodology for computation and statistical analysis, of sophisticated research instrumentation, and of shared facilities.

Highlighted in the following sections are a few accomplishments that illustrate the interdependence of research in the mathematical and physical sciences.

Table 4
Mathematical and Physical Sciences
Fiscal Years 1983 and 1984

(Dollars in Millions)

	Fiscal Year 1983		Fiscal Year 1984	
	Number of Awards	Amount	Number of Awards	Amount
Mathematical Sciences	927	\$ 34.76	1,047	\$ 41.13
Computer Research	292	29.34	287	33.63
Physics	493	89.14	502	104.11
Chemistry	962	67.63	976	79.23
Materials Research	815	81.08	794	96.05
Subtotal	3,489	\$301.95	3,606	\$354.15
Adjustment to Internat'l Awards	—	-1.51*	—	—
Total	3,489	\$300.44	3,606	\$354.15

*Obligations actually incurred under the Scientific, Technological, and International Affairs activity.
SOURCE: Fiscal Years 1985 and 1986 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) and NSF accounting records.

Mathematical Sciences

These sciences are best defined by what they investigate—those formal, abstract structures that reflect fundamental aspects of nature and can be broadly applied. Mathematical scientists look for patterns leading to the discovery of new structures. Once found, such structures can be used to model the behavior of natural phenomena. In their research, mathematical scientists have developed a language to describe the activities and laws of nature, and they have given us an indispensable foundation for science and engineering.

Research in the mathematical sciences continues to thrive. For example:

- Traditionally distinct areas of research such as analysis, algebra, number theory, geometry, topology, probability, and foundations are becoming increasingly interdependent.
- Applications of mathematics abound not only in such historically related areas as physics and engineering but also in fields newer to the uses of mathematics, among them economics and biology. This requires the constant development of new tools.
- A continuing creative tension exists between mathematical statistics and statistics viewed as a methodological science. As the use of statistics permeates modern life, new techniques are needed—along with careful analysis of their validity.
- The increasing power of the computer has enabled mathematical scientists to become more experimental. It has also allowed mathematical models to increase in size and complexity, replicating more effectively the realities they abstract and requiring increasingly sophisticated and thoughtful analysis.

NSF support is crucial to research in the mathematical sciences. The Founda-

tion provides nearly all of the federal funding for basic research in the traditional areas of mathematics. In applied mathematics and statistics, the NSF share is about 40 percent of the total funds for basic academic research, complementing programs of the Departments of Defense and Energy.

Number Theory and Elliptic Curves

Almost a decade of intensive, NSF-sponsored research has culminated in the solution of a problem in number theory that has puzzled mathematicians for over a century. Number theory, the study of integers and the relations between them, is a branch of mathematics notorious for problems that are easy to state and incredibly difficult to solve. Attempts to deal with one such class of problems, that of finding integer solutions to certain types of polynomial equations, led mathematicians to look at number systems more complex than the ordinary integers—for example, systems where squares can be negative. Establishing the arithmetic nature of these complex number systems is of great importance in providing insight and solutions to key questions.

One important characteristic of a generalized number system is its class number, a measure of how close the system is to having each of its “integers” be uniquely a product of its “primes.” The long-standing problem that has now been solved is to determine, for specific kinds of number systems (in this case, imaginary quadratic fields), a generic lower bound for the class number. This lower bound will allow researchers to determine all imaginary quadratic fields with a given class number, something they have been unable to do before now.

An important first step came several years ago when Dorian Goldfeld (then at MIT, now at the University of Texas in Austin) showed that the answer to the

class number problem for imaginary quadratic fields was tied to the existence of a mathematical object (known as an elliptic curve) with certain analytic properties. By reducing the problem to one of finding an elliptic curve with specific analytic properties, Goldfeld translated an arithmetic problem to an analytic one. Everyone believed the latter was easier, and several people attempted a solution. But it soon became apparent that a significant difficulty remained and only a major new result could close the gap.

Benedict Gross at Brown University and Don Zagier of the University of Maryland and the Max Planck Institute in Bonn have now provided an elliptic curve with the desired properties. The analytic condition that Goldfeld needed on such an elliptic curve had to do with the “order of vanishing” of its L-function at prescribed points in the complex plane. (The L-function of an elliptic curve is a complex-valued function defined by its structure.) Gross and Zagier showed that there are special points, called Heegner points, on any elliptic curve which control the order of vanishing of its L-function at the desired location. The arithmetic structure of the curve played a crucial role in defining these points.

Proof that the Heegner points influence the vanishing of the L-function required an intimate knowledge of number theory, algebraic geometry, and analytic techniques plus the tenacity to carry out delicate, lengthy, and time-consuming computations. Use of this proof in providing an elliptic curve to meet Goldfeld’s requirements is only the first of many possible ramifications. While closing out one chapter of number theory’s history, it opens the next.

Von Neumann Algebras and Knots

Von Neumann algebras were introduced in the 1930s to help study quantum mechanics. They remain a fertile field for mathematical analysis and continue to have physical implications. In fiscal year 1984, Vaughan Jones at the University of Pennsylvania made some startling dis-

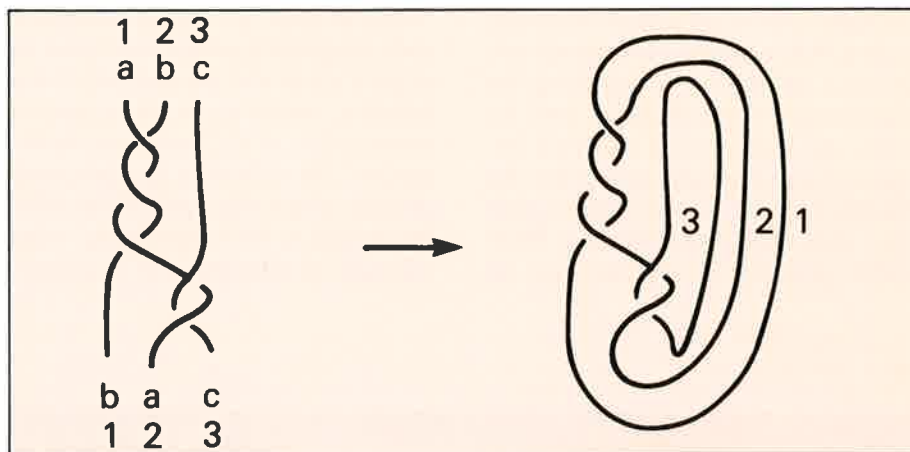
coveries about characteristics of von Neumann algebras. In the process, he made some wide-ranging discoveries in the seemingly unrelated area of topological knot theory.

The first attempts to list and classify knots as mathematical rather than mechanical objects were made in the late nineteenth century. (A knot is a closed curve in three dimensions. A link is a possibly interlocking system of knots.) Two knots or links are thought of as the same if one of them may be deformed to the other without cutting the strings. There is no systematic method for deciding when two given links are essentially identical.

Unable to decide when two links are the same, mathematicians have settled for rather powerful means of telling when they are not. Each link is assigned mathematical invariants. These are computable characteristics of the link that do not change when the link is deformed. Links with different invariants cannot be the same. The earliest link invariants were obtained by studying the topology of certain related spaces.

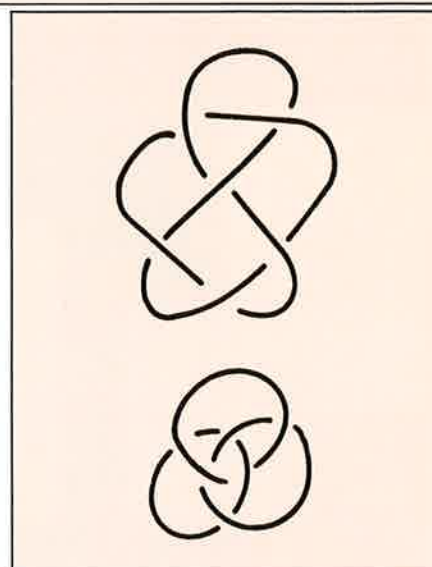
A different approach to distinguishing links removes the theory from its geometric context and places it in an algebraic one. One way of defining a link is to begin with a braid of intertwined strings and pull the ends around to create a link. Algebraic structures called "braid groups" describe the string interchanges which result in a given braid and provide an algebraic process for determining when different braids give the same link. This method of studying knots is difficult to use directly, but it is tempting to try to exploit the group structure since the braid groups are known to occur in many contexts, including statistical mechanics.

As Jones investigated von Neumann algebras, he defined certain finite-dimensional algebras and noticed that their defining relations were similar to those for the braid group. The new ingredient in Jones's treatment is the description of a trace function that can be used to recover numerical information. Computing the trace of a braid representation results in a new invariant for the associ-



Braid to link. One way of defining a link is to begin with a braid (intertwined strings) and pull the ends around to create a link. The figure seen here illustrates this process. String c starts and ends in position 3 so that it is tied to itself. Strings a and b switch locations and so become tied to each other. The link then has two components, one consisting of original string c and the other strings a and b tied together.

Knots and Links. A knot is a closed curve in three dimensions. A link is a system of knots, possibly interlocking. Knots and links can be adequately represented by a projection onto a plane, which allows us to draw pictures of them. Although knots and links can be surprisingly complicated, two relatively simple examples appear in this figure. The first is the knot designated 6_2 . The second is the link designated 6^3_2 , also known as the Borromean rings.



ated knot or link; this invariant is significantly more sensitive than earlier ones. Using an NSF-funded Sage 4 computer, Jones was able rapidly to compute his invariant for many links, avoiding extensive and time-consuming hand computation. The trace invariant and its easy computability have allowed Jones, his graduate student Hans Wenzl, and others to solve some long-standing problems in knot theory and to make progress on many others.

Restoration of Images

Image restoration, the process of recovering the original picture from a blurred or degraded image, is important in a variety of situations. Whether interpreting satellite pictures or asking for computer identification of an object,

scientists are interested in keeping computation time low (requiring some sampling techniques) and accuracy high. They naturally turn to concepts from statistics and probability for help in solving such problems.

Donald Geman at the University of Massachusetts and his brother Stuart Geman at Brown University have introduced new methods for restoring images. Their work is largely inspired by methods from statistical mechanics for investigating the way large systems evolve and behave.

The Gemans built their image-restoration process on the statistical concept of a Markov Random Field. MRFs describe how the probability of an occurrence at one point of a field is affected by conditions at neighboring locations. Lo-

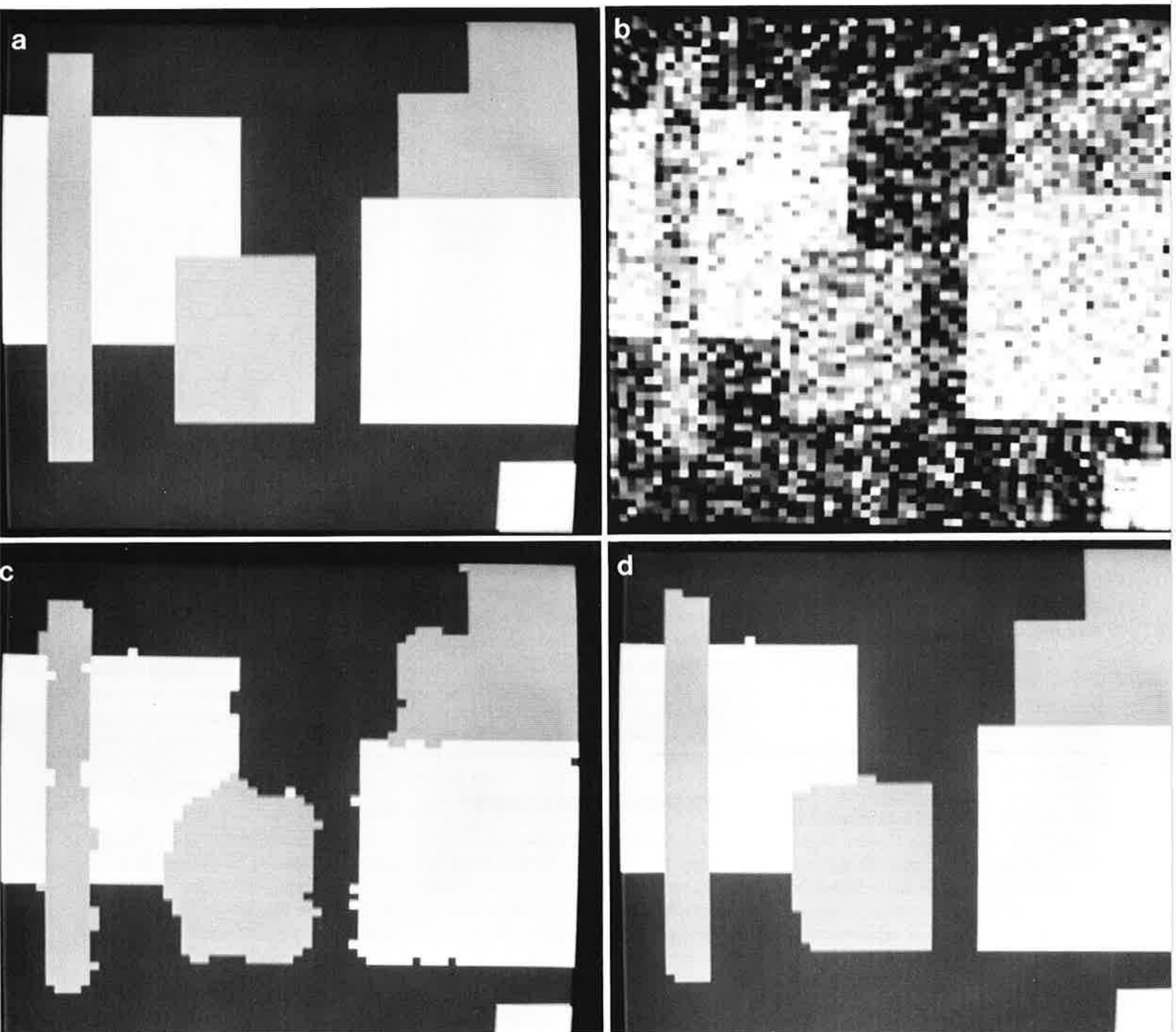
cal characteristics are difficult to specify, making MRFs hard to use in image restoration. However, by exploiting the equivalence between MRFs and the Gibbs distribution (from statistical mechanics) over the same state space, the Gemans were able to overcome this problem. They then combined these MRF-Gibbs models with what they call the

“Gibbs Sampler” to overcome the need to make simplifying assumptions about the original image and the methods of degradation, while maintaining ease of computation in the image-restoration process. By following the imaginary physical system represented by the Gibbs distribution to the lowest energy states (through a process similar to annealing in

the physical model), the Gemans obtained precisely the desired estimates of the original image for the degraded data.

Early computational experiments have shown the efficacy of these methods for image restoration. The process adapts readily to parallel computation, and more NSF-funded experiments to exploit that characteristic are under way.

Image Restoration. These photos illustrate the Gemans' image-restoration process. The researchers started with a hand-drawn image (a), which was then degraded or blurred (b). Their process, borrowing heavily from statistical mechanics, restored the degraded version to its original detail (c&d). This kind of research is important in such areas as computer identification of objects and interpretation of satellite pictures.



Computer Research

Computer research continues to be one of the most exciting areas in the mathematical and physical sciences. It incorporates both intellectually challenging, abstract subjects and practical applications. Some of its effects are subtle: The way information is presented can influence the way the material is understood. A graphic representation, for example, can illuminate relationships that otherwise are not evident.

In one application of this concept, program-development systems can use novel presentation techniques to improve programmers' productivity. In another, robots dealing with real objects can be supplied with internal representations of those objects, improving the robots' ability to manipulate them.

To which of these and other problems the powerful, emerging techniques of parallel or simultaneous computing will apply is still to be determined. The future of parallel computers is the subject of a burgeoning collaborative exploration by government, industry, and universities, as described later.

"PECAN"

A good program-development system can edit, translate user language into machine language, and automatically correct (debug) certain kinds of errors. A Brown University project called PECAN creates all these abilities from a simple definition of the programming language to be used. This project, under the direction of Steven Reiss, has led to a family of systems to develop programs, demonstrating that:

- Modern computer technology can make programming more productive.
- Simple specifications can generate complex systems.
- A practical system can use advanced concepts, such as multiple views and reverse execution.

The program-development systems

generated by PECAN are designed to make effective use of an upcoming technology—powerful personal computers with high-resolution graphics displays. The systems offer simultaneous views on the computer screen of the user's program, the program's semantics, and its execution.

PECAN systems include such features as these: (1) With multiple views, the user can edit in any of the available views and immediately see the changes in all of them; (2) With debugging, the program can be run backward as well as forward; (3) With the use of graphics, reverse execution is done by reconstructing the previous output. PECAN has shown that these and other concepts can enhance future productivity in programming more complex applications efficiently.

Spatial/Temporal Reasoning

Progress in the field of artificial intelligence requires formalizing knowledge in such a way that computer programs can use it. The main obstacle to this goal is not the volume of knowledge required but the difficulty of formalizing many dimensions of knowledge efficiently. Some of these dimensions we take for granted—especially formalisms for reasoning about space (the shapes, positions, and functions of objects) and time (causal relationships among objects and events).

Consider this example: Most of us know the shape of the Eiffel Tower but not the precise location of every girder in it. Still, we have enough approximate knowledge to reason about whether the tower might puncture a low-flying blimp, and if so, where the collision would occur.

To reason about an event like this, we need two things: a way to represent approximate knowledge of shape, and a way to keep track of motion and event sequences. A research group at Yale Uni-

versity, under the leadership of Drew McDermott, has been studying both of these. A computer program written by Ernie Davis, now at New York University, represents the shapes of objects as polygons that approximate actual shapes. Bradley Alpert and David Miller have revised that program and run it on a computer smaller than the one on which it originated. The program deals only with two-dimensional objects and hence would not be suitable for reasoning about the Eiffel Tower problem. At this writing, the researchers are extending that program to three-dimensional objects.

A data structure for keeping track of event sequences is called a *time map*. As new events are observed or inferred, they are added to this map, along with their effects. Some events undo the effects of others. For instance, inflating a blimp causes the fact "Pressure = 10 psi" to become true, and puncturing a blimp causes this fact to become false. Yale's Tom Dean has written a time map that can keep track of such inferences.

A major application of time maps is in robotics, especially the construction of mobile robots. They must roam around a partly unknown environment, make and execute plans, and verify that such execution is on track. In 1984, Drew McDermott's group modified a Heathkit robot so that it could communicate with a larger computer; the group also studied ways to extract better information from the robot's sonar rangefinder. Algorithms developed by David Miller and Stan Letovsky take several readings from the sonar, extract an enhanced picture of the robot's distance from walls and furniture, then decide what place in the robot's internal map fits that picture—and hence where the robot probably is at a particular time.

This research is important in developing the robot's ability to analyze its environment.

Parallel Processing Research Council

Over the years an amazing technological evolution has produced faster

and faster computers. Still, some problems are so complex that they are beyond the reach of today's supercomputers. For example, the speeds needed for such problems as the autonomous control of a vehicle will require different parts of a computer to handle subproblems simultaneously, or in parallel.

Various designs for parallel computers have been proposed and some of them tested on a small scale. But these designs cannot be evaluated without large-scale experiments, which require close cooperation between the academic researchers who originate designs and the industrial researchers who apply them. Furthermore, while the United States leads the world in basic research in parallel computing, it currently lags in applying that research.

Toward these ends, a Workshop on University/Industry/Government Collaboration in Parallel Computing was held in Washington, D.C. late in 1983 under NSF sponsorship. The workshop identified two critical needs:

1. An indepth program to maintain U.S. leadership in research on parallel computing.
2. Development of a way to apply the concepts emerging from research on parallel computing.

Specific problems attend these goals. The large-scale experiments that are essential in evaluating new concepts are difficult to mount, and a knowledge base for effective application of parallel computer architectures is absent. The workshop recommended specific steps to overcome these problems and a forum through which universities, industry, and government can collaborate. That forum has since been created—the Parallel Processing Research Council, which is aiding the formation of partnerships in research and development and collaborations on large-scale experiments. The Council also is looking into ways to provide:

- A funding base for both large-scale experiments and basic research in parallel computing.

- Access by researchers to large-scale computer facilities and to the engineering technology needed to design and use computer systems, both hardware and software.

The Council's Executive Committee

includes representatives from Honeywell, the Sperry Corporation, IBM, Digital Equipment Corporation, MIT, the Universities of Illinois and Texas, and the U.S. Departments of Energy and the Navy.

Physics

Through this discipline we study the basic properties and behavior of matter and energy—from the structure and interaction times of elementary particles to the size and age of the discernible universe, from temperatures close to absolute zero to the highest energies (customarily expressed as temperatures) of particles accelerated between galaxies. The range of everyday human experience falls in a narrow band between these extremes; increasingly sophisticated measuring apparatus extends our senses over the rest of the range.

To describe this broad range in the properties and behavior of matter, physics needs only a few basic laws and constants. We continue to study these basic laws to understand their implications more fully, to determine any limits on their applicability, and to find possible substructures and further unifying simplifications.

NSF supports research covering the entire span of activities in physics; in FY 1984, grantees made great progress in unifying and understanding the fabric of the universe. First, university groups have new information on the properties of quarks, the elusive building blocks of elementary particles. Second, a research team found that, contrary to all previous predictions, the motion of these quarks, when placed in a heavy nucleus, is strongly distorted. And third, researchers are building experimental prototypes for a totally new detector of gravitational radiation. The theory of general relativity predicted gravitational radiation 70 years ago; its effects have been

deduced, but gravity waves have yet to be detected directly.

Quark Properties: New Information

The so-called "Standard Model," the most widely accepted theoretical model of elementary particles, has successfully described the smallest structures of matter. Quarks are the particles that make up, for example, the proton and neutron; gluons are the particles that bind quarks together. The Standard Model specifies the way quarks decay into other quarks. Much of the activity in this field is aimed at testing and improving this model.

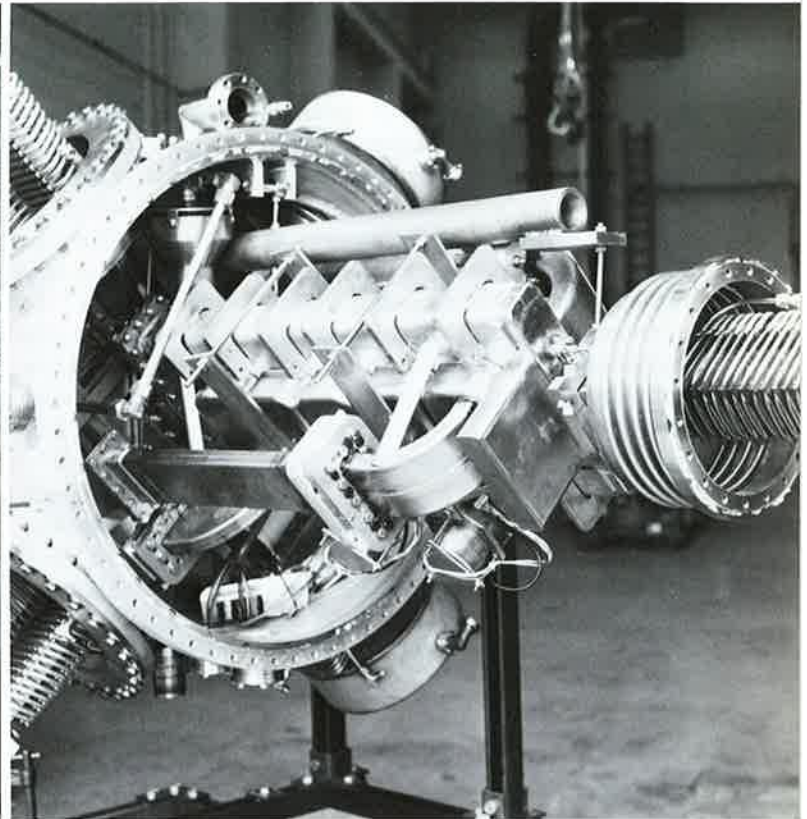
Last year there were five known quarks and some evidence for the expected sixth. The well-established heavy quarks, called "charm" and "bottom," have been studied intensively for several years. The bottom quark has been studied in this country mainly at Cornell University's Electron Storage Ring, an NSF-supported facility.

During FY 1984, NSF-supported researchers using the Cornell facility determined, in a remarkably accurate measurement, the mass of a particle made of a bottom quark and an "antibottom" quark—the upsilon particle. The uncertainty in the measurement was very low—only an order of magnitude less accurate than the measured mass of the electron, a stable particle.

Scientists working at the Cornell facility have also contributed to our growing knowledge about the charm quark. At laboratories around the world, re-



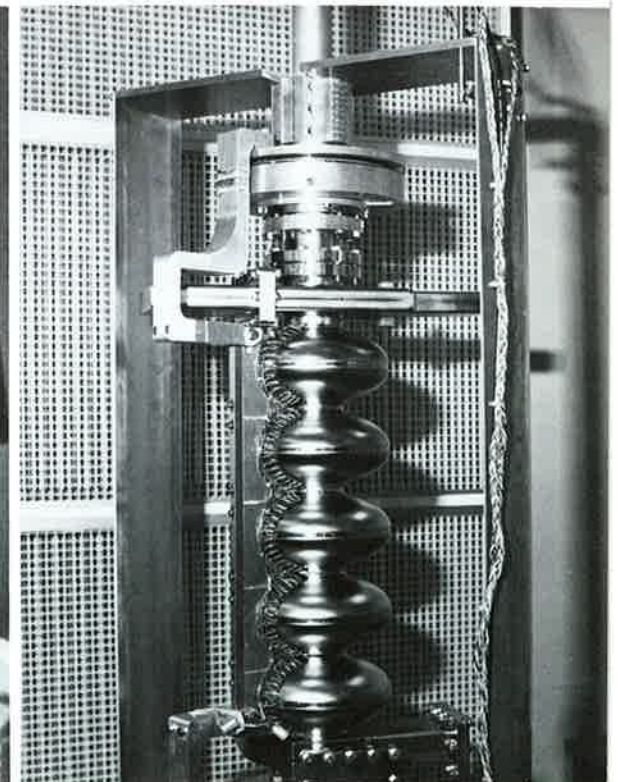
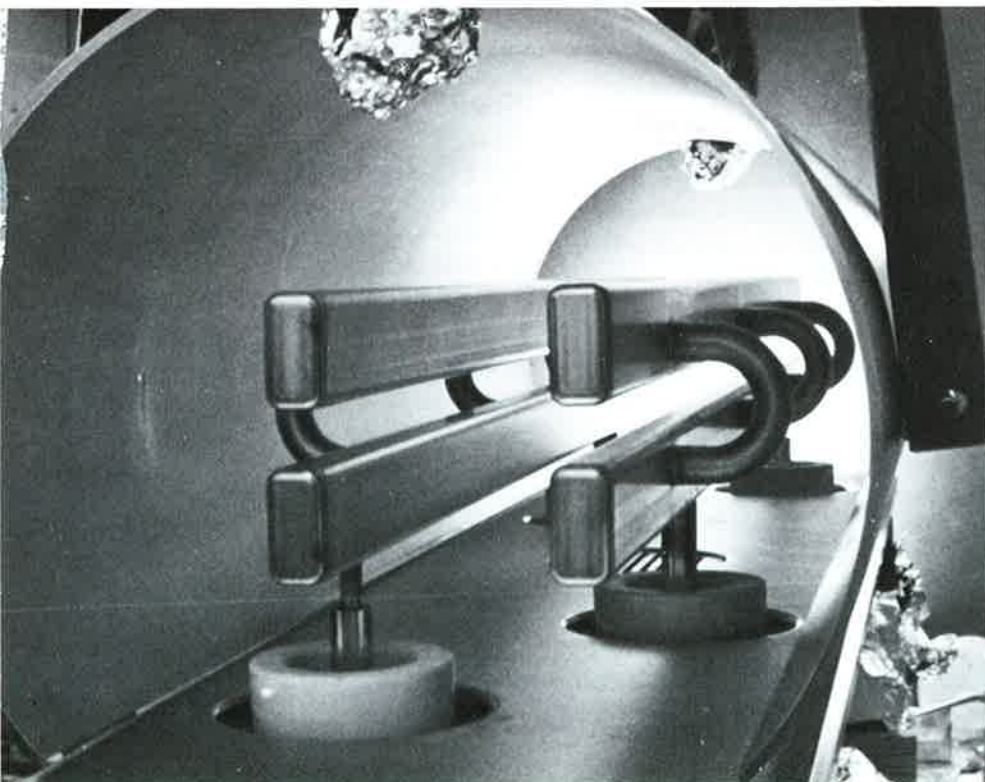
Detector Construction. A researcher at the Cornell Electron Storage Ring (CESR) assembles the large central drift chamber. It tracks charged particles in an experiment designed to study the basic structure of matter.



Superconducting R.F. Cavities. A group at Cornell's CESR laboratory is doing major work on superconducting radio frequency (R.F.) cavities, needed for future generations of electron accelerators. Shown above is a model used last year in beam tests.

Beam-Control Elements. Electrostatic separator plates are used to position the electron and positron beams in the Cornell Electron Storage Ring.

New Design. A design being tested at Cornell at this writing is pictured below.



searchers have looked for, and occasionally found, evidence of a particle composed of a charm quark and another quark, called "strange." This particle, named "F meson," was predicted by theory long before there was any experimental evidence for its existence. During 1983, NSF-supported experimenters at Cornell reported properties for the F meson that did not agree with previous experimental results. Their evidence has now been corroborated by experiments at other labs. This significant result clarifies previous confusion about the particle's properties and further confirms the Standard Model.

Last year NSF-funded scientists from the University of Houston, Northeastern University, and the University of Utah, collaborating at the Stanford Linear Accelerator Center at Stanford University, measured the lifetime of the bottom quark. The measured value, about 1.5 picoseconds, is about the time it takes light to travel half a millimeter, and about five times longer than the Standard Model can readily accommodate. The long lifetime of the bottom quark—combined with other results on the decay behavior of this quark—adds to the difficulty of explaining within the Standard Model the observed violation of a fundamental principle of symmetry.

In an experiment at Illinois's Fermilab, a collaboration of scientists from Fermilab, Princeton University, and the French Center for Nuclear Studies—led by Bruce Weinstein of the University of Chicago—investigated this key question of the violated symmetry principle. While refining our understanding of the symmetry violation, Weinstein's group expects to provide a further important test of the Standard Model.

Quark Motions in Nuclei

One of the most intriguing questions of the past 10 years is how the forces that hold quarks in the nucleon are revealed in the complex structure of nuclei. Murray Gell-Mann and George Zweig predicted the existence of quarks in the 1950s, and

experimenters at the Stanford Linear Accelerator first observed these pointlike components of the nucleon in the early 1970s. Exactly how quarks influence the structure of nuclei, which are made up of bound systems of nucleons, has remained unknown.

A surprising discovery came out of a collaboration of physicists studying the scattering of very energetic particles called muons. These investigators, collectively called the European Muon Collaboration, found that, contrary to all previous predictions, the motion of quarks in a heavy nucleus like that of an iron atom changes relative to quark motion in a nucleon. An NSF-supported group from Washington, D.C.'s American University, led by Raymond Arnold, has confirmed these results and extended them to a large number of nuclei. This group used the electron accelerator and a newly refurbished detector at the Stanford Linear Accelerator to study highly inelastic electron scattering from a variety of nuclei, from hydrogen to gold. While the American University results generally agree with the European work, they also show that the quarks' change in motion is related, in a systematic way, to the size of the nucleus.

Since, according to the successful theory of quantum chromodynamics, individual quarks remain confined in their original nucleon, these results could have profound implications for the study of both nuclear structure and fundamental nuclear interaction. The tantalizing phenomena could add much to our understanding of a variety of important astrophysical processes.

Detecting Gravity Waves

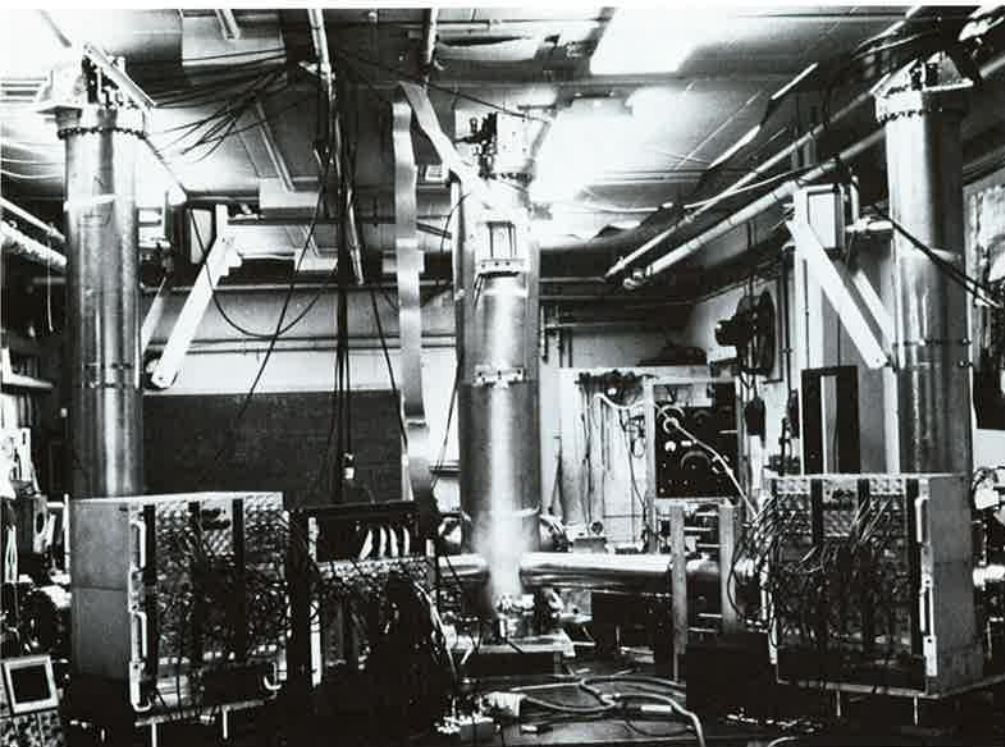
Albert Einstein first predicted gravitational waves in 1918. By 1960, technology had advanced enough for physicists seriously to consider verifying the existence of this elusive and weakly interacting form of radiation. But building a suitable receiver is an extraordinary challenge, since the observable effect of a passing gravitational wave is an infinitesimal

oscillation in the length of a detector. Theoretical estimates of the gravitational wave flux naturally bathing the earth suggest that the strongest waves to arrive frequently would probably correspond to a length change in the detector of one part in 10^{22} . The most sensitive receiver built so far, constructed by William Fairbank's group at Stanford University, can measure the change in length of an aluminum bar by one part in 10^{18} .

Since it is the *fractional* change in length that is important, a long detector—where the absolute size of the corresponding length change will also be larger—is obviously an advantage. This has led the groups under Ronald Drever and Kip Thorne at Caltech and Rainer Weiss at MIT to consider detectors 5 kilometers long. These would be large L-shaped vacuum tanks with mirrors at the ends. Gravity waves would cause one arm of the tank to contract while the other expands. Bouncing laser beams back and forth between the mirrors at the ends of the arms and then combining the beams to produce an interference pattern would allow measurement of changes in the lengths of the arms.

To demonstrate the feasibility of this technique, Drever and Weiss have built two prototype detectors, based on interferometer technology, which are respectively 40 meters and 1 meter in size. These prototypes provide test beds for designing displacement sensors, vacuum and optical systems, and laser stabilization schemes—all vital parts of the detection receiver systems.

During 1984 there was encouraging progress on both of these prototype instruments. Interferometer operation has shown sensitivity to displacements on the order of 10^{-14} centimeters within a frequency bandwidth of 2,500 Hertz. This corresponds to a displacement of one-tenth the diameter of a proton! Such sensitivity is at the theoretical limit of the capability of the present prototypes. Within the next year, the installation of higher-powered lasers will give a tenfold increase in sensitivity.



Gravitational Wave Receiver. This prototype of a laser interferometer gravitational wave receiver was built at MIT. It is a test bed for the design of increasingly sensitive detector receiver systems to measure the effects of passing gravity waves. The three vertical cylinders are vacuum cans containing mirror suspension systems. Also visible are complex electronic instruments, which permit very precise measurements of displacements.

Chemistry

Chemistry is a broad, multifaceted discipline. It provides new substances, ranging from complex organic pharmaceuticals and agricultural chemicals to sophisticated inorganic solids that control the flow of electrons to make computers work. It unravels the intricate atomic combinations that nature has assembled over millennia. Through chemistry we discover catalysts that make it possible to duplicate and modify complex natural substances, and to convert materials such as petroleum and coal into basic chemical compounds. Chemists also create synthetic macromolecules and develop valuable information about the structures and actions of natural biomacromolecules.



The heart of chemistry is synthesis—the ultimate source of most of the new materials that serve society. Progress in chemical synthesis depends on comparable advances in other branches of chemistry, including catalysis. Research in that area is concerned with the way certain substances change rates of chemical reactions without being altered themselves.

Catalysis research also involves many subfields, including surface chemistry, solid-state chemistry, organic and inorganic synthesis, photochemistry, electrochemistry, bioorganic chemistry, and chemical engineering—along with the contiguous fields of solid-state physics, surface physics, biology, and biochemistry. Thus catalysis research may be viewed as a unifying force in chemistry.

An estimated 20 percent of the U.S. gross national product is generated through use of catalysis. It is directly involved in producing more than \$100 billion worth of goods per year in the United States.

Catalysis Research. At ULCA, a team headed by Joan S. Valentine (far left) gained new information in the field of catalysis, a critical area concerned with changing the rate of a chemical reaction. The researchers found that the ions of some metals in a certain solution can help form epoxides, important in the process of catalysis. The research also sheds light on how metal ions are used by biological systems to influence chemical reactions involving oxygen.

As oil resources are depleted, catalysts will be used extensively to tap new energy sources such as heavy oils, coal, oil shale, tar sands, lignites, and biomass. The raw, or starting, materials of a coal-based chemical industry will probably be carbon monoxide and carbon dioxide. This means we must develop new, low-energy catalytic reactions to convert these small carbon-containing compounds to the larger ones that form gasoline or fuel oil. Many of the reactions that could accomplish the conversion are thermodynamically feasible. However, because of the kinetic stability of the starting materials, the reactions are slow in the absence of suitable catalysts.

The remarkable specificity of nature's catalysts—the enzymes—has stimulated interest in imitating them synthetically. Like enzymes, many synthetic materials can catalyze specific reactions. Somewhat typical of this approach to catalysis research is NSF-supported work reported recently by Joan S. Valentine at UCLA.

Valentine and her colleagues (postdoctoral associate Catherine C. Franklin and graduate students Reuel VanAtta and Alice F. Tai) found that ions of such metals as copper, manganese, cobalt, and iron in acetonitrile (methylcyanide) solution helped form epoxides—three-member rings, each containing two carbon atoms and one oxygen atom. The discovery may have commercial significance because epoxides are important raw, or starting, materials. More important, says Valentine, the research advances understanding in another area—how biological systems use metal ions, particularly those of iron and copper, to catalyze reactions involving oxygen.

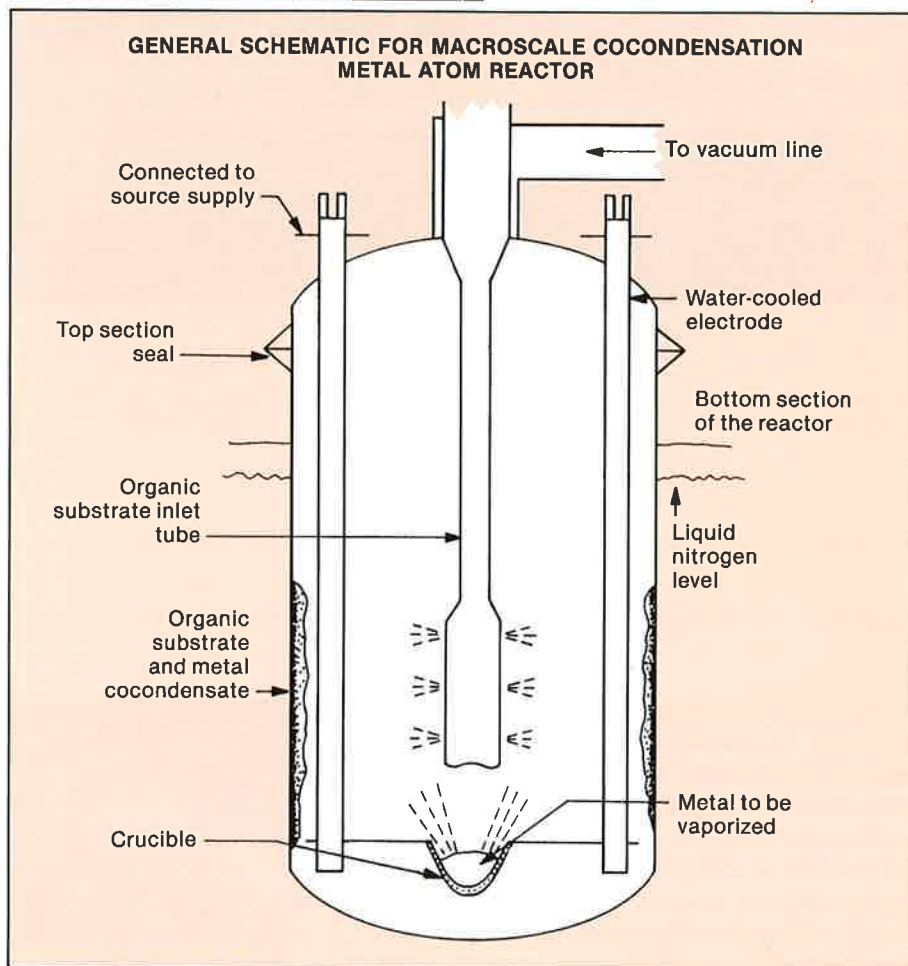
Descriptions of the other catalysis research follow.

Bimetallic Catalysts

What seems to be the first known case in which one metal catalyzed another was discovered by Kenneth J. Klabunde and graduate student Yuzo Imizu at Kansas State University. These investigators found that small pseudo-organometallic



SMAD Technique. Kansas State University chemist Kenneth J. Klabunde (right) and graduate student Allen Olsen examine a bimetallic catalyst prepared by the solvated metal atom dispersion (SMAD) procedure. Research at Kansas State has shown that small particles containing both manganese and cobalt can catalyze certain hydrocarbon reactions more effectively than can particles containing cobalt alone. This finding could lead to the production of commercially important hydrocarbons. In the background of the photo is an electron-beam metal vapor reactor used in this work and purchased with NSF funds. (Figure is a general schematic for a macroscale metal atom reactor.)



particles containing both manganese and cobalt catalyzed certain hydrocarbons (alkenes) much more effectively than did similar particles containing only cobalt. (Note, however, that the manganese apparently had very little catalytic activity, indicating that the results were somehow produced by interaction of the two met-

als.) The new bimetallic particles are also better catalysts than commercial ones or similar particles containing other metals.

This new manganese-cobalt catalyst is but one in a series of unusual products from Klabunde and his coworkers, using a technique known as solvated metal

atom dispersion (SMAD). The technique was designed to take advantage of the fact that small clusters of metal atoms are fundamentally different and more reactive than clean metal surfaces. SMAD catalysts are typically more reactive than conventional catalysts and in many cases show unusual specificity—like the naturally occurring enzyme catalysts mentioned before.

The SMAD catalysts are prepared in a vacuum flask, its walls cooled to -196 degrees centigrade by liquid nitrogen. The metal to be studied is vaporized in a small electric crucible in the center of the flask. At the same time, small quantities of a solvent are also admitted to the flask. The solvent vaporizes rapidly, then condenses on the walls of the flask along with the metal atoms. Varying heating rate and the relative proportions of metal solvent make it possible to regulate the size of the metal clusters that are formed. These “bare” metal clusters—called bare because they have no covalent metal-carbon or metal-hydrogen bonds—can be extremely reactive. Aluminum atoms, for example, react with methane at -263 degrees centigrade; this phenomenon has not been observed for single atoms of any other metal.

Klabunde's discovery is especially important because of recent interest in producing catalysts that contain both “early” and “late” transition metals—that is, those at the beginning and end of the row in the periodic table. Investigators hope that such combinations might lead to production of hydrocarbons having significant commercial value.

Catalyzing “Syngas”

In a joint project at the University of Michigan, M. David Curtis of the chemistry department and Johannes Schwank of the chemical engineering department discovered a new process to produce benzene from synthetic gasoline, or syngas. Benzene is used to prepare literally hundreds of industrially important chemicals and is also added to gasoline to increase octane rating. Syngas is a mixture of hydrogen and carbon monoxide produced from coal.

The key to this project's success was discovery of a new series of metal clusters that were highly specific in their catalyzing activity. These clusters produced carbon chains with ring structures like benzene, rather than the straight chains that usually result from joining carbon atoms together sequentially.

The new syngas catalysts were prepared from heat-treated clusters consisting of the metal molybdenum, together with iron, cobalt, or nickel. The cluster framework was held together with sulfur atoms. The iron-molybdenum catalyst caused syngas to react at relatively low temperatures and pressures. The major products were methane (C_1), ethane (C_2), and benzene (C_6). (The notation— C_1 , etc.—shows the number of carbon atoms in the molecule.) Very few contaminating by-products were observed. This

product distribution was exceedingly unusual, since most syngas catalysts join the carbons together sequentially and form a mixture of by-products.

The discovery has some exciting aspects. First, the production of benzene directly from syngas is significant—at this writing there are no reported syngas catalysts that form benzene as a primary product. Also important is the fact that benzene products occurred without significant formation of the intervening hydrocarbon by-products.

These catalyst compositions were originally developed to overcome sulfur poisoning, a severe problem with current catalysts. The unique selectivity of the compositions came as a pleasant surprise, and the researchers' attention turned to understanding this unusual behavior. They anticipate, however, that the catalysts will also show resistance to sulfur poisoning.

Finally, molybdenum is a constituent of both industrial catalysts and certain important enzymes, and the new molybdenum cluster catalysts may show unusual properties in other applications as well. In this regard, the University of Michigan results represent the first instance in which a metal cluster showed a reaction behavior totally unlike that of its constituent metals under steady-state conditions.

Cluster Analysis. At the University of Michigan, discovery of a new group of metal clusters that enable highly specific catalysis has made possible the production of benzene from synthetic gasoline. M. David Curtis (right), a chemist, and Johannes Schwank (second from right), a chemical engineer, discuss an experiment with two graduate students. Benzene, widely used by industrial chemical plants, also can increase the octane rating in gasoline. (Photo by Bob Kalmbach, from the University of Michigan News and Information Services)



Materials Research

This is a multidisciplinary field aimed at a deeper understanding of the properties of materials—their composition and structure and the interactions between their constituents. Materials research provides the essential scientific underpinning for technological advances. In many cases, a particular technology is limited by our inability to produce materials with certain properties—high strength, corrosion resistance, or special electronic characteristics, for example. Research on materials is also at the forefront of areas yielding major conceptual advances. Among these are:

- Universal principles of phase transitions (changes in the physical state of matter).
- The nature of the amorphous state, in which solids are glassy, having no regular atomic arrangements.
- The behavior of materials with sub-micron dimensions. (A micron is one-millionth of a meter.)

Materials research deals with solids, glasses, and liquids; this includes metals and their alloys, ionic crystals, organic polymers, semiconductors, composite and multiphase mixtures, and biological materials. Because materials scientists must prepare and characterize materials accurately, they need highly sophisticated instrumentation. Disciplines such as metallurgy, ceramics, chemistry, physics, mathematics, and various branches of engineering may all be involved in materials research. The materials studied and disciplines applied are diverse, but the basic problems, phenomena, and theory involved are strongly interrelated.

Although single-component materials remain an active subject of study, the emphasis in materials research is shifting toward more complex materials and systems. Surfaces, interfaces, small particles, thin films, intricate microstructures, and quasi one- and two-

dimensional materials are important examples.

NSF supports materials research through individual grants in various scientific and engineering disciplines. The Foundation also funds instrumentation projects and large interdisciplinary labs, national facilities at seven sites around the country, and groups of collaborating investigators. Some important questions addressed by this community are:

1. How can mechanical properties of materials—strength, fracture, fatigue, and the like—be understood in terms of microscopic mechanisms, such as defects in the atomic structures of crystals and chemical segregation?
2. What is the fundamental nature of nonlinear, nonequilibrium phenomena such as the growth of crystals, turbulence in fluids, and solitary waves?
3. What are the detailed atomic and molecular structures of amorphous (glassy) solids, and how do these affect magnetic, electrical, optical, and mechanical properties and resistance to chemical attack?
4. What principles determine the thermodynamic properties of materials near such phase transitions as melting, realignment of magnetic axes, or the onset of superfluidity in liquids at temperatures near absolute zero?
5. What central features of surfaces and interfaces control electrolytic behavior, catalytic activity, electronic device performance, surface reconstruction, corrosion, erosion, and wear?

More and more, both theorists and experimentalists are able to confront the complexity of real materials and the relationship of their properties to their structures. For example, in studying the way different materials act as catalysts, a fun-

damental question is what effect the size of metal atom clusters has on catalytic activity, especially when the clusters have fewer than 20 to 50 atoms.

R. P. Andres at Purdue has been exploring this question; he has developed a method for growing metal clusters ranging in size from 5 to 500 atoms in a medium of inert gas. Using this approach, researchers can alter both metal cluster size and support material. The technique has considerable potential for creating unique catalytic and electrocatalytic materials.

In a second example, the arrangement of atoms on surfaces is the focus of two important, and independent, advances by theorists. Both involve calculations that help us understand the structure of solid surfaces. S. A. Louie and his group at the University of California, Berkeley have calculated the physical and chemical properties of surfaces such as diamond and tungsten. J. D. Joannopoulos and his colleagues at MIT have found a different way to determine the surface structure of semiconductors.

Unless we explore the atomic structure of surfaces, interfaces, and amorphous materials, our knowledge about their physical properties will remain limited. Without structural information, for example, understanding and controlling catalytic processes or surface behavior such as corrosion would be impossible. This central theme of materials research—understanding how the macroscopic behavior of materials is related to their microscopic structure—is illustrated in the next section of this chapter.

Polymers Conduct Electricity

The advent of manmade polymers—long chains of identical molecules—is in some ways the most important step ever taken in synthetic chemistry. These polymers are now found in everything from stockings and fishing lines to tires and shoes. Despite the significance of these materials, their electrical properties are quite unremarkable. The electronic conductors we know about are still made

largely of metal, which is expensive, often difficult to work with, and quite heavy. In recent years, researchers have been working toward polymers that would also be electrically conductive or even superconductive. Such materials would have many uses, from antistatic guards to plastic wires to electronic devices.

A Northwestern University team of chemists, materials scientists, and electrical engineers has prepared and studied a new class of electronically conductive, organometallic polymers. These materials (called polymetallophthalocyanine oxides) form stable, conductive polymeric chains that are also inexpensive, long-lived, and easy to prepare.

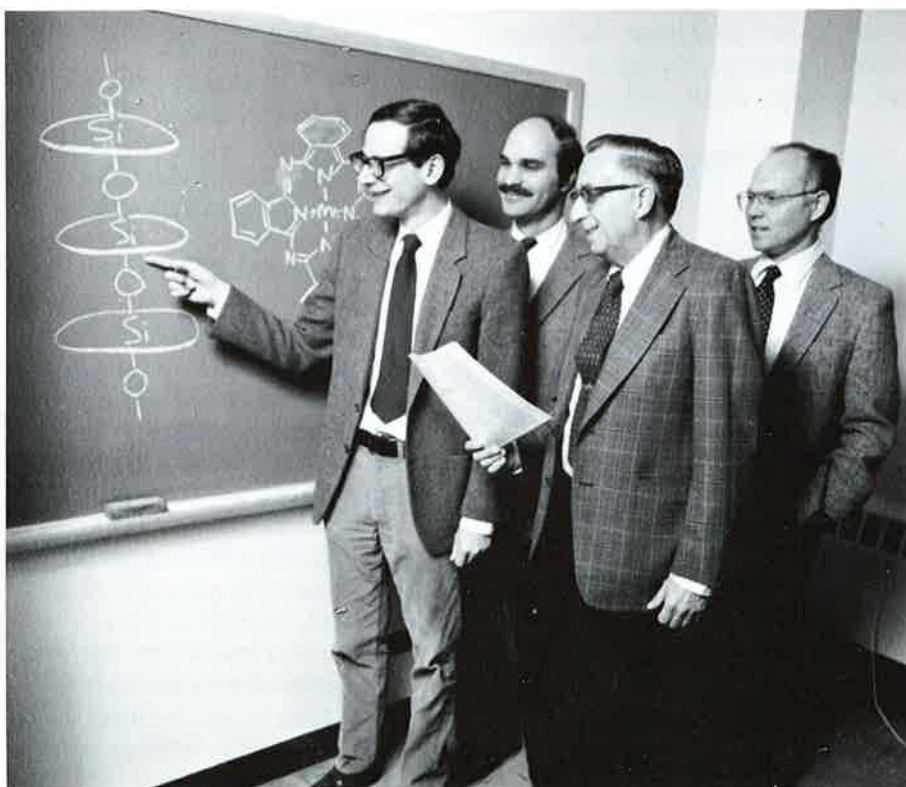
Tobin Marks, Mark Ratner, Stephen Carr, and Carl Kannewurf have been investigating the way these chains are built. Improving a polymer's conductivity and stability involves understanding just

what makes the chains function as they do. Kathy Doris, a student in the Northwestern group, has been able to prepare the two smallest subunits of the conductive polymer, individual molecules which consist of single and double sites for connection to the chain. These are called monomer (one) and dimer (two), respectively.

The team has found that the polymer's properties, notably its conductivity, are quite straightforwardly related to the properties of the monomers and their linkage. In particular, the combination of two monomers to form a dimer is precisely the same interaction that creates conductivity in the bulk crystal. This interaction has been studied at different temperatures and distances and in different solvents. The Northwestern researchers have found that by studying the properties of the monomers and dimers, they can predict the most interesting



Ion Implantation. A new way to change the surface chemistry and properties of solids is with ion implantation, which enables polymers that can conduct electricity to be synthesized. By bombarding polymers with certain ions, Mildred Dresselhaus of MIT brought about spectacular increases in the conductivity of polymers whose insulating qualities were normal before. Industry has shown interest in this work because changes in a polymer's properties indicate that new materials with selected characteristics can be produced. (MIT photo by Calvin Campbell)



Polymeric Chains. A research team at Northwestern University is studying a new class of organometallic polymers that can conduct electricity. The properties of two of the smallest subunits of the conductive polymer have been analyzed, giving the researchers critical information that could help improve a polymer's conductivity and stability. Discussing their research are (from left) chemists Tobin J. Marks and Mark A. Ratner and engineers Carl R. Kannewurf and Stephen H. Carr.

property of the final polymer—conductivity.

This is the first time that scientists have been able to produce a conductive polymer as well as its simplest building blocks, and to understand how those blocks interact to yield the overall properties of the polymer.

Another way to synthesize electrically conducting polymers is with ion implantation, a new technique to change the surface chemistry and properties of solids. Mildred Dresselhaus at MIT observed dramatic increases in the electrical conductivity of normally insulating polymers when she bombarded them with the ions of a different species. Dresselhaus then measured the extent to which the conductivity of several different ion-implanted polymers depended on temperature. Her work has attracted considerable interest from industry because it shows that a polymer's properties can be modified to synthesize new materials with specifically desired properties.

The Atomic Staircase

High-resolution images of the surface structure of bulk materials would help us solve many problems in surface science. The standard technique for looking at surfaces is scanning electron microscopy (SEM), but this method can rarely be used to resolve details less than 100 angstroms or so in size. Information on the variation of crystal structure at a particular surface is correspondingly limited. An atom-sized step on a metal surface, for example, might be only about two angstroms high.

To overcome these limitations, researchers at Arizona State University have revived the technique called reflecting electron microscopy (REM). It provides a means of looking at surfaces by diffracting beams of electrons from them at very low angles. By analogy, the headlights of an automobile clearly illuminate the jumps and dips in the road 45 to 91 meters ahead. REM was first tried in the 1930s, produced some interesting results in the 1950s, but was then abandoned because of experimental diffi-

culties. SEM appeared to be more promising.

Graduate student Tung Hsu, working at Arizona State first with Sumio Iijima and later with John Cowley, has shown that REM can be used effectively with commercial electron microscopes. Hsu has obtained the first clear images of atom-high steps on metal surfaces. The images are severely foreshortened because of the grazing angle of incidence made by the electron beam with the surface. If a surface is reasonably flat, however, this is not too serious a defect.

REM has already provided several insights into the surface structure of metals. As seen with REM, for example, the smooth, rounded surface of a gold crystal divides into a spectacular array of planes. At a higher resolution, each planar facet consists of regular arrays of steps 1 atom high and several angstroms wide. For minerals and for semiconductors such as gallium arsenide, REM can show how defects in the crystal below the surface influence the arrays of steps on that surface. In short, REM gives us new in-

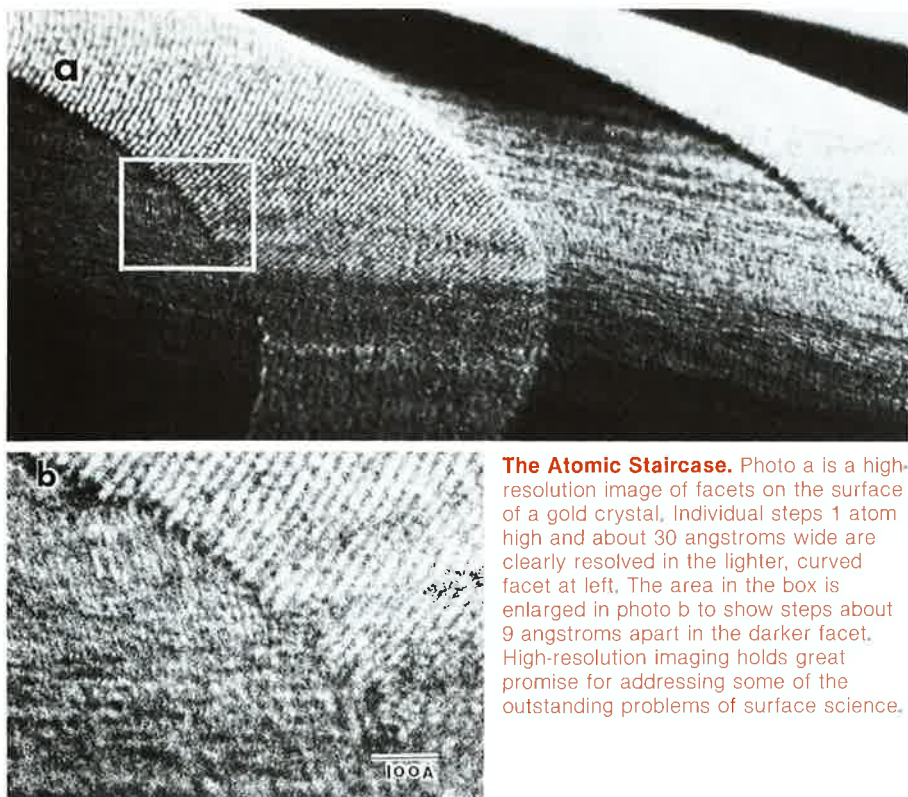
sights into surface structure and tells us how this is related to surface composition. It may become a powerful tool for investigating major problems in catalysis, degradation of materials, and the fabrication of electronic devices.

Tunable Infrared Lasers

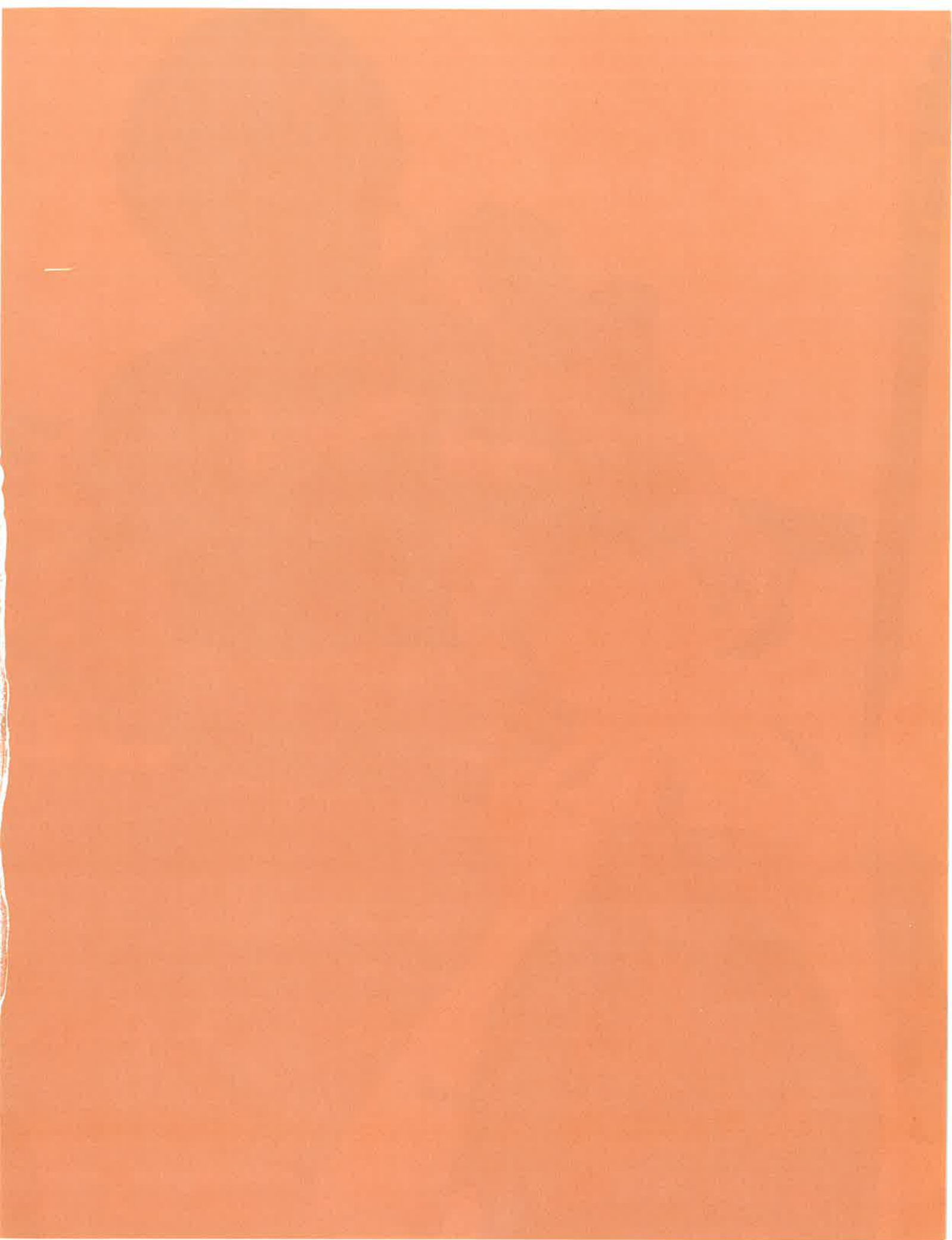
Lasers whose light can be tuned to exact frequencies commonly use dyes in organic solvents as the laser material. A major drawback, however, is that these lasers do not operate in the near-infrared range. This disadvantage should be overcome through a recent development: wavelength-tunable lasers, based on color centers in alkali halide crystals. If an ion in such a crystal is dislodged, its place may be taken by an electron, introducing a defect into the crystal. This defect is a color center; it produces a characteristic color in an otherwise transparent crystal. The color-center lasers developed at this writing are based on complex crystal defects.

L. F. Mollenauer and his associates at Bell Laboratories, among others, have developed tunable lasers in the 2.2 to 3.3 micron—or near infrared—range, based on color centers associated with lithium or sodium ion defects. Lasers of this type are now commercially available. With NSF support, Fritz Luty at the University of Utah has developed lasers tunable in the 0.8 to 2.0 micron range, based on another class of complex defects in crystals. Luty and his colleagues have obtained stable and broadly tunable laser operation in the 1.4 to 1.7 micron range, using potassium chloride and bromide crystals doped with the semimetallic element tellurium. The active defects can be produced in a number of hosts.

Luty has also reported the first observation of infrared emission from vibrating molecules in solids, using alkali halide crystals with a small concentration of molecular cyanide defects. This phenomenon opens up new ways to develop tunable infrared lasers, which are likely to be important in molecular spectroscopy, fiber optics, and other research areas.



The Atomic Staircase. Photo a is a high-resolution image of facets on the surface of a gold crystal. Individual steps 1 atom high and about 30 angstroms wide are clearly resolved in the lighter, curved facet at left. The area in the box is enlarged in photo b to show steps about 9 angstroms apart in the darker facet. High-resolution imaging holds great promise for addressing some of the outstanding problems of surface science.





Science and Engineering Education

5

NSF's Directorate for Science and Engineering Education, re-established in FY 1984, works to help assure that the nation meets its future demand for scientists and engineers. The directorate also is concerned about students who enter the work force from high school, and it promotes general scientific literacy in our increasingly technological society. This reflects the growing public awareness that technical education—from elementary school through the graduate level—is vital to our nation.

Programs in FY 1984 focused especially on improving science and math education for all students, a goal set by the National Science Board's Commission on Precollege Education (*Educating Americans for the 21st Century*, September 1983). NSF also emphasized state and local initiatives and partnerships among school systems, universities, industry, professional associations, and others—a grassroots commitment to excellence.

Also in 1984, the Congress mandated a program to improve instructional equipment at predominantly undergraduate institutions for the following year. NSF plans to make these awards in time for the 1985-86 academic year.

Precollege Education

Justice Oliver Wendell Holmes once said: "Through our great good fortune, in our youth our hearts were touched with fire." Gifted teachers can certainly touch students' hearts with fire. But teachers and students also need high-

quality instructional materials and opportunities to learn about recent developments in science, mathematics, and technology. In FY 1984, the NSF emphasized the following areas in its precollege activities.

Table 5
Science and Engineering Education
Fiscal Year 1984
(Dollars in Millions)

	Fiscal Year 1984	
	Number of Awards	Amount
Graduate Research Fellowships	153	\$20.31
Precollege Sci. and Math Education	276	37.13
Total	429	\$57.44

SOURCE: Fiscal Year 1986 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) and NSF accounting records.

Developing Materials —and Teachers

This effort supports better instructional materials for students and teachers, improved ways of preparing teachers, development of new technologies, and research on learning and teaching. As examples, NSF-supported projects investigated improving instruction through computer software; simulating laboratory experiments on computers; and tailoring instructional materials to the needs of special students, such as women, minorities, and the physically disabled.

Presidential Teaching Awards for Excellence. President Reagan made the first of these awards in a White House ceremony early in FY 1984. Honors went to 104 secondary-school teachers, one in science and one in mathematics from each state, the District of Columbia, and Puerto Rico. To support their excellent work, NSF gave each teacher's school \$5,000 for programs that the teacher directs. Each instructor received a microcomputer and software donated by private industry. A second group of teachers was similarly honored near the end of FY 1984.

Honors Workshops recognize outstanding teachers and offer them specialized training to improve programs in their schools. Several hundred teachers, representing the entire range of science and mathematics education, attended workshops in FY 1984.

Local and Regional Teacher Development, a new program in FY 1984, helps communities offer training and professional development for elementary and secondary teachers in science and mathematics. Directed toward teachers who have had limited opportunities to keep abreast in their fields and toward those shifted into subjects for which they lack training, the program encourages local commitment to provide those opportunities.



White House Ceremony. President Reagan greets spectators during ceremony in which awards were presented for excellence in teaching. One of the winners was Angie L. Matamoros (center), science teacher at Coral Springs High School, Coral Springs, FL. Looking on at left is George Keyworth, presidential science advisor.



Teaching Award Winner. NSF Director Erich Bloch (left) congratulates Timothy Howell, mathematics teacher at St. Paul's School, Concord, N.H. Howell is one of more than 100 secondary school teachers who won Presidential Teaching Awards for Excellence in late 1984.

Special Activities

The Foundation also encourages science and mathematics education beyond school walls by supporting museums and television programs such as public TV's "3-2-1 Contact," serving as an information resource for teachers and school planners, and funding studies on the status of precollege math and science education.



Beyond School Walls. NSF promotes the understanding of science and engineering by funding various museums. Here a student listens to an iguana's heartbeat at the Lawrence Hall of Science, University of California, Berkeley. (Photo by Charles Frizzell)



Preparing for Experiment. Science students heat and shape glass tubing for an experimental apparatus at the Oregon Museum of Science and Industry. (Photo courtesy of the Museum)

Hair Raising. The forces of static electricity make this young girl's hair stand on end during a man-made lightning demonstration at The Franklin Institute Science Museum. (Photo by B. D. Vaughan, from the Institute)



Franklin Institute. Weather permitting, bubble-blowing workshops take place daily in the Institute's outdoor Science Park, an exhibit area that features more than 40 devices having to do with water, measurement, and the sun. (Photo from the Institute)



"Hangin' In." Inside a chamber at the Alabama Space Camp, a student finds out how zero gravity feels.



Other Programs

Graduate Fellowships

Graduate fellowships target the nation's best and brightest students in science, mathematics, and engineering. Since 1952, almost 22,000 graduate students have received support from NSF for advanced study; they include 9 Nobel laureates, 5 winners of the NSF Waterman Award, many members of the National Academies of Science and Engineering, an astronaut who walked on the moon, and the woman who graduated at the top of the U.S. Naval Academy's class of 1984. Graduate fellows have recently pursued more applied fields—such as engineering, mathematics, and computer science—as career opportunities in these fields have expanded.

In FY 1984 the Foundation offered 600 students three-year graduate fellowships (100 more than the previous year). Altogether, 1,458 students are being supported on tenure this year, including new awardees. Another 1,422 applicants received Honorable Mention.

Since 1978, NSF has also offered Minority Graduate Fellowships to broaden the range of career options available to minorities. Last year the stipend for both graduate and minority graduate fellowships went from \$6,900 to \$8,100 and the cost-of-education allowance, paid to the fellow's institution, rose from \$4,000 to \$4,900. As a result of Congressional action the awards will increase to \$11,100 and \$6,000, respectively, in FY 1985. With these changes, the fellowships are now competitive with those offered by most other federal agencies and by nongovernmental organizations.

Following are examples of work by recent graduate fellows:

- *Ronald I. Dorn*, in geography at UCLA, developed a new method for dating rock surfaces. The technique, used on stone tools in the

Mohave Desert, showed that some tools were about 22,000 years old.

- *Christopher P. Silva*, in electrical engineering at the University of California, Berkeley, analyzed theorems for nonlinear differential equations—for use in designing electrical circuits.
- *Nelson E. Bickers*, in physics at Cornell University, focused on condensed matter theory and superconductivity—both important in developing the next generation of computers.
- *Martha Hayden*, in genetics at the University of Washington, investigated the mechanisms of genetic recombination. These mechanisms can now be studied with new methods that use electron microscopy and techniques involving enzymes.

Minority Graduate Fellowships

These fellowships aim to expand the ranks of scientists and engineers in minority groups that have been historically underrepresented. In FY 1984, NSF awarded 60 minority fellowships, and another 157 applicants received Honorable Mention. NSF got 525 applications that year—40 percent more than in FY 1983. In addition, 106 students continued minority fellowships begun earlier. The awards support three full years of graduate study but may be used over five years, allowing students to incorporate teaching and research assistantships into their education.

The fellowships are open to American Indians, Blacks, Hispanics, Native Alaskans, and Native Pacific Islanders. Applicants must be U.S. citizens, and fellowship awards are based on merit. Panels of scientists assembled by the National Research Council of the National Academy of Sciences review and

evaluate applications; NSF then makes the final selections. The fellowships may be used at any appropriate institution of higher education in the United States or abroad.

Twenty-one women received Minority Graduate Fellowships in FY 1984 and thirty-nine recipients were men. Following are some examples:

- *Karen A. Singmaster*, a Ph.D. candidate in chemistry at the University of California at Berkeley, investigated systems to adjust the energy of a laser, an aid to the study of chemical reactions. These systems activate selected parts of a molecule and could control the reaction products.
- *Alexander S. Moad*, a Ph.D. candidate in organismic and developmental biology at Harvard University, focused on seedling growth patterns in tropical rain forests, a key factor in the ecology of those areas.



Fellowship Winner. Lawrence D. Beshear, an Oklahoma State University student who is beginning his master's degree work in electrical engineering, has been selected to receive a Minority Graduate Fellowship from the National Science Foundation. The award includes an \$8,100 cash stipend and up to \$4,900 for tuition and fees for each of the next three years of study. (OSU photo)

Focus on College Instrumentation

Science and engineering students—majors and nonmajors alike—must work with appropriate, up-to-date equipment if they are to become truly involved in the methods of scientific research. Moreover, whether the subject is molecular biology, submicron electronics, or astronomy, many aspects of science cannot be taught effectively without exposing students to the instrumentation that has made recent discoveries possible.

The predominantly undergraduate colleges have historically been strong contributors to the nation's supply of scientists and engineers. Enrollment in many of these institutions is small, but a significant portion of their seniors continue at the graduate level, many of them in science and engineering. These schools also play a key role in preparing precollege math and science teachers and educating future business and government leaders. But, as teaching institutions, the predominantly undergraduate colleges receive little if any research and equipment funds from the federal government. With rapid changes in scientific instrumentation in recent years, much of their instructional equipment has become obsolete.

By improving the quality of instructional equipment in these undergraduate institutions, NSF's new College Science Instrumentation Program will help them to build and maintain strong, high-quality science and engineering instruction for all their students. Graduates will then be better prepared for technical jobs, precollege science teaching, graduate study, and positions as scientifically informed business and government leaders.

Congress mandated this program in the Foundation's FY 1985 appropriation, signed into law on July 18, 1984. It is the first effort specifically aimed at undergraduate education since the Science and Engineering Education Directorate was reestablished. The Congress added \$5 million to NSF's science education

budget to fund the new activity's first year.

The Foundation will provide funding on a 50 percent matching basis; it can be used to acquire state-of-the-art scientific equipment for instruction, to replace and upgrade existing equipment, or to develop new instruments. Proposals will be evaluated on merit, and the Foundation plans to make the final awards in time for the schools to buy equipment for the 1985-86 academic year.

Math Education: NEW GOALS

The liberating objective of scientific literacy cannot be accomplished by a one-time effort. . . . What is required is the permanent, sustained, and increasing commitment of the American scientific community.

So concluded a National Research Council report, *The State of School Science*, in 1979. Four years later, the National Science Board's Commission on Precollege Education defined that commitment for the professional societies of the nation's 3.1 million scientists, engineers, and mathematicians. The Commission recommended that those groups get involved in developing curricula, finding ways to recognize excellent teachers, instructing both students and teachers about computers, and working with private industry, museums, and schools to promote math and science education.

The work of the Conference Board of the Mathematical Sciences is an example of how professionals can play an active role. With support from NSF, the Board held a three-day conference* in

November 1983 to define specific goals for improving math education and ways to meet those goals. Out of this meeting came a valuable report, *NEW GOALS for Mathematical Sciences Education*, which spelled out in detail specific recommendations on curriculum, teacher-support networks, communicating standards and expectations, mathematical competence and achievement, remediation, and faculty renewal. The report also discusses the first steps needed to carry out these recommendations and spotlights areas requiring funds.

In the area of standards and expectations, for example, the study proposed a three-week "writing workshop," with broad representation from the professional mathematical sciences and related lay communities. Workshop participants would create a series of pamphlets designed to help school systems and consultants in teacher evaluation and training, test evaluation and selection, curriculum content, student testing, computer literacy, and other topics. Participants would also develop a series of teachers' guides to improve the teaching of mathematics by grades, rather than through specific texts. A guide for ninth-grade algebra, for example, would not only outline topics that should be covered but would also explain the relevance of each, offering significant examples and applications.

NEW GOALS has been widely distributed by the American Mathematical Society. Other professional associations are following similar courses in physics, earth sciences, chemistry, and other fields.

Monitoring the Status of Science Education

In FY 1984, NSF contracted for several studies to monitor the status of science education in the United States. Included among these are:

- Joint support by NSF and the National Institute of Education to the *Educational Testing Service*. ETS is researching, developing, and

*Participants included the President of the National Council of Supervisors of Mathematics; the President and President-elect of the National Council of Teachers of Mathematics; the President of the American Mathematical Association of Two-Year Colleges; the Director of Education for the Society of Actuaries; and representatives of the American Education Research association, the Sloan and Ford Foundations, and several mathematics and statistics associations.

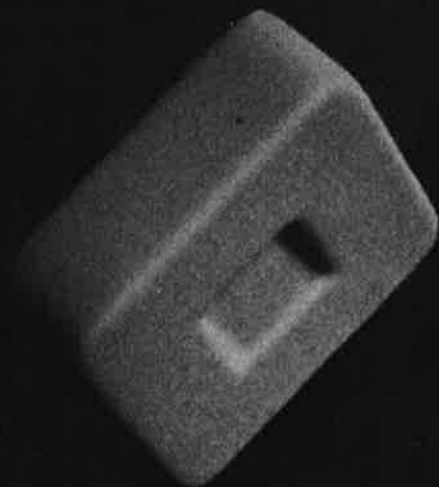
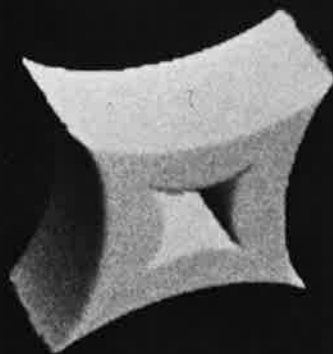
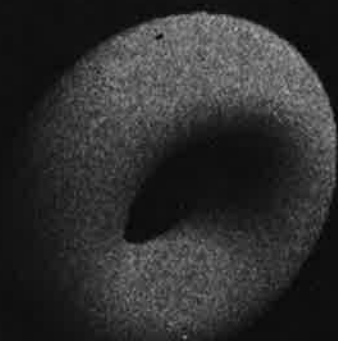
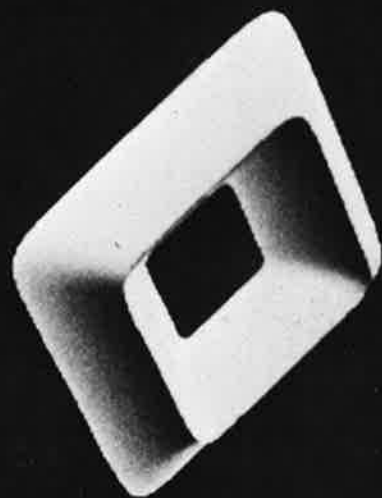
field testing some innovative assessment techniques to measure achievement in higher-order skills in mathematics, science, and technology. Previous national assessment surveys have indicated a decline in these skills, especially among high-ability students. The ETS research focuses on developing new survey techniques to measure the problem-solving, critical-thinking, and reasoning skills that

students may have acquired. The results will be part of a National Assessment of Educational Progress to be issued in the spring of 1986.

- A two-year contract with the *National Academy of Sciences/National Research Council* to (1) develop better indicators of the condition of precollege science and math education; (2) review major research studies and databases; (3)

identify information gaps and recommend new studies; and (4) work with selected states and localities in creating effective monitoring systems. NAS/NRC is developing a framework for an efficient set of indicators, filling in that framework with existing data to provide a baseline, and suggesting what other data and analyses are needed for a continuing picture of science and math education.





Scientific, Technological, and International Affairs



These programs bridge scientific disciplines and link researchers from various sectors. Through these activities, NSF maintains a broad outreach to diverse elements of the U.S. science and engineering community. This breadth of perspective strengthens the Foundation's efforts to promote a vital scientific and technological enterprise in the nation.

Program goals are to:

- Aid cooperative efforts among academic and industrial research performers and users.
- Enhance the work of U.S. researchers by encouraging cooperative activities with foreign scientists and engineers.
- Improve information resources for decision making on science and technology issues.
- Extend research opportunities for female, minority, and handicapped researchers, as well as faculty from predominantly undergraduate institutions.

Industrial Science and Technological Innovation

Through these programs, the Foundation fosters the development of new technology by encouraging private investment in university research. It encourages cooperation between academic and industrial scientists, supports high-

risk research by small science and technology firms, and evaluates university/industry interaction and the process of technological innovation. Three examples of this research effort follow.

Table 6
Scientific, Technological, and International Affairs
Fiscal Years 1983 and 1984

(Dollars in Millions)

	Fiscal Year 1983		Fiscal Year 1984	
	Number of Awards	Amount	Number of Awards	Amount
Industrial S & T Innovation	50	\$14.51	209	\$18.03
Internat'l Coop. Sci.	86	4.65	421	12.93
Policy Research and Analysis	93	4.27	63	4.58
Science Resources Studies	49	3.65	34	4.18
Research Initiation and Improvement	131	11.77	109	9.04
Subtotal	409	\$38.85	836	\$48.76
Adjustment to Internat'l Awards	—	5.28*	—	—
Total	409	\$44.13	836	\$48.76

*Actual obligations incurred under the Scientific, Technological, and International Affairs activity.
SOURCE: Fiscal Years 1985 and 1986 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) and NSF accounting records.

Cooperative Research Centers

Universities and industry often have similar research interests. NSF promotes their collaboration in a growing number of centers where groups of industrial firms cofund with NSF a university research program that is relevant to industry. With this support, a center can start a program of wide scope, often too large for any one company to undertake alone. Long-term support increasingly becomes industry's responsibility as NSF funding phases out over a five-year period. A center's research generally reflects a university's special strengths in science and engineering, as well as multidisciplinary activities designed to meet industry's needs.

At this writing, there are 20 cooperative centers (see list) and 10 more are planned. The 20 get most of their support from more than 200 private companies and involve 250 university faculty members, 30 postdoctoral scientists and engineers, 300 graduate students, and 40 undergraduates, along with 200-plus advisers and about 400 project monitors from industry.

The Rutgers Center for Ceramics Research illustrates the accomplishment of these young institutions. Since its start in 1982, it has grown rapidly and received strong state support for equipment as well as research. An application for a patent on a unique way to increase the bond strength of ceramic material has come from this research. The center has also been involved in the industrial processes used to bond refractories and allied products.

Other developments:

- By 1985 two more centers will join the three already solely supported by industry. At this writing, industry provides more than \$10 million a year in support for the centers, while federal aid is less than \$3 million.
- State governments, recognizing the value of these centers for regional economic development, have contributed an extra \$10 million to operations in New Jersey, Ohio, and Massachusetts. More support for centers in other states is planned at this writing.
- Universities have pooled their re-

sources to form consortia in some states. For example, the University of North Carolina has teamed with Duke University for a Center in Monoclonal Lymphocyte Technology. The New Jersey Institute of Technology, Stevens Institute, Rutgers University, Princeton University, and the University of Medicine and Dentistry of New Jersey have formed a Center for Toxic/Hazardous Waste Management. These consortia in particular seem to attract broad and strong support from industry.

- Other federal agencies, finding this kind of work valuable to their missions, are cofunding or otherwise supporting the centers.

Small Business Innovation Research

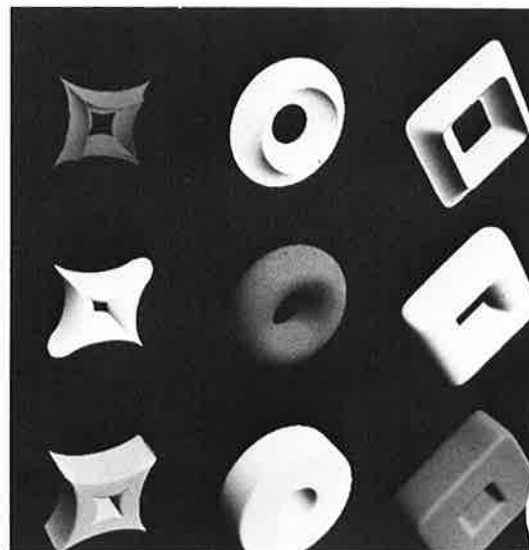
Small, high-technology firms are especially efficient in converting advanced research into innovation and technology. Thus NSF supports high-quality research proposals in nearly all areas of science and technology from firms with 500 or fewer employees. The Foundation aims to achieve substantial public benefits by emphasizing advanced research that is high-risk, innovative, and industrially relevant.

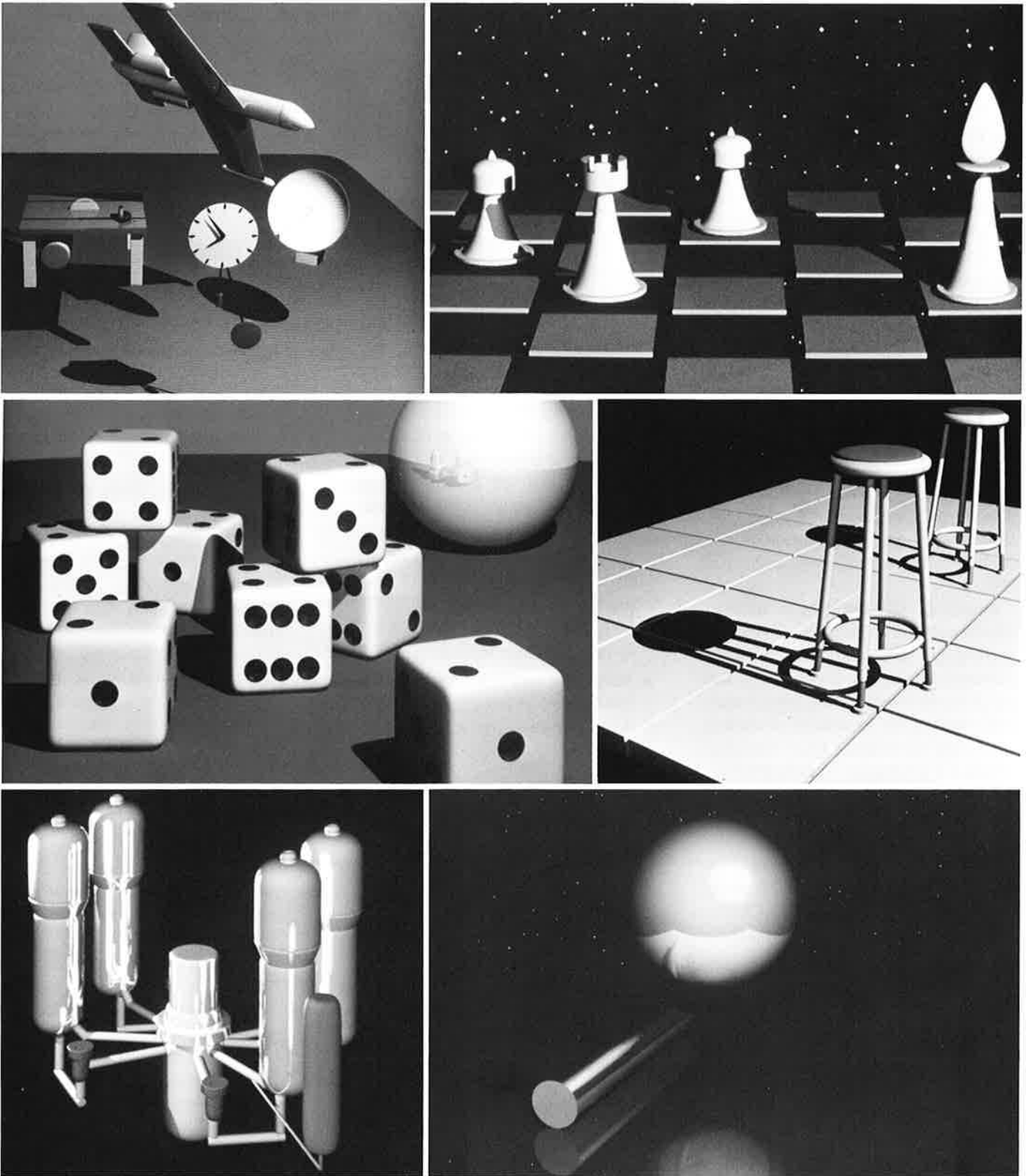
This highly competitive research support goes through three phases:

- Phase I - to determine if the research appears technically feasible and

IUCR CENTERS (AS OF OCT 1, 1984)

LOCATION	SCIENCE AREA	YEAR INITIATED
MASSACHUSETTS INST. OF TECHNOLOGY	POLYMERS (PROCESSING)	1973
RENSSELAER POLYTECHNIC INST.	COMPUTER GRAPHICS	1979
UNIVERSITY OF MASSACHUSETTS	POLYMERS (PROPERTIES)	1980
OHIO STATE UNIVERSITY	WELDING	1980
CASE-WESTERN RESERVE UNIVERSITY	POLYMERS (APPLIED)	1981
UNIVERSITY OF RHODE ISLAND	ROBOTICS	1982
NORTH CAROLINA STATE UNIVERSITY	TELECOMMUNICATIONS	1982
RUTGERS UNIVERSITY	CERAMICS	1982
GEORGIA INSTITUTE OF TECHNOLOGY	MATERIALS HANDLING	1983
WORCESTER POLYTECHNIC INST.	AUTOMATION TECHNOLOGY	1983
TEXAS A & M UNIVERSITY	HYDROGEN TECHNOLOGY	1983
PENNSYLVANIA STATE UNIVERSITY	DIELECTRICS	1983
COLORADO SCHOOL OF MINES	STEEL PROCESSING	1984
UNIVERSITY OF WASHINGTON	PROCESS ANALYTICAL CHEMISTRY	1984
NEW JERSEY INST. OF TECHNOLOGY	TOXIC/HAZARDOUS WASTE MANAGEMENT	1984
UNIVERSITY OF ARIZONA	OPTICAL CIRCUITRY	1984
WEST VIRGINIA UNIVERSITY	FLUIDIZED BED RESEARCH	1984
NORTHWESTERN UNIVERSITY	TRIBOLOGY	1984
U. OF NORTH CAROLINA/DUKE U.	MONOCLONAL LYMPHOCYTE TECHNOLOGY	1984
UNIVERSITY OF ARIZONA	MICROCONTAMINATION CONTROL	1984





Ray tracing. These computer-generated images were produced using a technique known as ray tracing. It produces high-quality, realistic looking imagery. Lighting phenomena such as reflection, refraction, and shadowing are accurately simulated. Image-generation techniques such as ray tracing are used in a wide variety of applications, from computer-aided design and manufacturing to advertising and entertainment. These images are an example of the research taking place at the Rensselaer Polytechnic Institute's Center for Interactive Computer Graphics.

whether the firm can do high-quality research. Phase I awards are for up to \$40,000 for six months, with 102 awards made in 1984. (About one in eight Phase I proposals is funded.)

- Phase II - the principal research project; the 36 awards made in 1984 averaged \$100,000 a year for two years.
- Phase III - the pursuit of commercial applications, after NSF support ends, with nonfederal funds usually obtained from larger industrial or venture-capital firms.

Since 1977 private follow-on funding for Phase III has exceeded \$60 million. The research has produced important publications, patents, new products and processes, joint ventures, even new businesses. More than 40 percent of the grantee firms have had 10 or fewer employees, and 50 percent of them are under five years old. Universities collaborated in more than half of the projects in 1984.

Awards in 1980 and 1981 to the Merrick Corporation of Nashville, Tennessee (including a subcontract to Vanderbilt University) brought striking results. Research on the methodology for automatically sensing the location of a welding joint—via intelligence from electrical signals of a welding arc—resulted in 4 inventions, 2 patents, and 22 publications.

This sensing system was the first of its kind to be developed and made commercially available. It also resulted in innovative technology, the sale and licensing of equipment and knowledge to Cincinnati Milacron and three other companies, foreign sales and licensing, and substantial investment in Merrick. Virtually every manufacturer of arc-welding robots intends to offer some version of sensing based on this research.

Improving Productivity

NSF seeks to enhance American technology by studying the processes of technological innovation and their relationship to industrial productivity and economic growth. These studies, both inhouse and extramural, have improved

our understanding of the deployment and diffusion of technological innovations. Research priorities of both theoretical significance and national importance are: (1) the implementation of process technologies (e.g., manufacturing and office automation, and (2) assessment of state and local initiatives to develop high technology. NSF expects these two research

emphases to constitute most of the extramural research effort over the next three years.

For inhouse work, one major focus is an evaluation of the cooperative research centers mentioned before. This project will develop a comprehensive, longitudinal database on university/industry cooperation.

Research Initiation and Improvement

National strength in science and technology requires a broad range of human and institutional resources. The Foundation promotes the full development of these resources through programs that:

- Give research opportunities to female, minority, and physically handicapped scientists and engineers.
- Increase research efforts by faculty in undergraduate institutions.
- Strengthen research capabilities in institutions and regions with low participation in research and development activities.

These programs encompass all science and engineering disciplines. In addition, NSF also supports research on ethical problems and value conflicts in the conduct of science and technology.

Key achievements are described below.

Undergraduate Institutions

Over 90 percent of all U.S. institutions of higher education are predominantly undergraduate. The quality of education they provide in science and engineering is critical to the nation's well-being. In FY 1984, the Foundation awarded more than \$38 million for faculty research at mainly undergraduate institutions, a jump of 27 percent over FY 1983. NSF expects to increase such aid still more during FY 1985.

With its support, NSF helps strength-

en the bond between research and undergraduate instruction, as the following examples show:

- *Charles Carlin, Lynn Buffington, Jerry Mohrig*, and other faculty at Carleton College in Minnesota have been preparing students for graduate training in chemistry with a spectrometer purchased with \$106,300 from an NSF grant (plus \$30,000 in matching funds from the college). The instrument helps faculty and students study the electrochemistry of ring compounds, the shapes of sugar/protein molecules, and other chemistry topics.
- *John Chapman* at California State University, Northridge, has added to our knowledge of variations in the sun's output and the effect of sun spots on this output. His measurements of solar irradiance are made with an instrument carried on NASA's Solar Maximum Mission Satellite.
- *William Stone* at Trinity University in San Antonio, Texas has been learning how immune systems evolved by studying those systems in a marsupial that separated from the human branch of the evolutionary tree over 100 million years ago. His project has involved undergraduate students in basic laboratory research.
- *George O'Clock* and *Charles*



Carleton College Team. Shown left to right are Lynn A. Buffington (assistant professor of chemistry), student Peter K. Lee, Jerry R. Mohrig and Charles H. Carlin (professors of chemistry), and student David G. Alberg. They are seen in the instrument room of the Hall of Science, Carleton College, Northfield, MN. Buffington, Carlin, and Mohrig were recipients of a Research in Undergraduate Institutions (RUI) program grant in FY 1984. (Photo by Nancy Ashmore, Carleton College)

Gruber at Mankato State University in Minnesota, using a scanning electron microscope purchased with NSF grant money, have been studying failure mechanisms in semiconductors. Those failures are often due to chemical reactions caused by contamination. Their research may greatly improve quality-control techniques in producing integrated circuits. The microscope is being incorporated into a new undergraduate curriculum in electrical engineering.

In its goal to strengthen research and education in undergraduate institutions, the Foundation has boosted its efforts to inform such colleges of funding opportunities and ways to help faculty develop stronger proposals. In FY 1984, NSF staff visited more than 60 smaller institutions and held 24 regional outreach forums for their faculties.

Stimulating Research

Since 1978, NSF has worked to improve research capabilities in selected states where activity in research and development lags. Under a program called EPSCoR (Experimental Program to Stimulate Competitive Research), seven states received planning grants to assess their strengths and weaknesses in science and technology and to develop five-year research improvement programs. After reviewing the plans for scientific merit and local commitment to them, in FY 1980 the Foundation awarded \$3 million each to Arkansas, Maine, Montana, South Carolina, and West Virginia. Four years later, NSF made its final funding increments (totaling \$2.2 million) to these states for the last two years of their programs.

Some recent achievements of the EPSCoR program include:

- *Jack Horner* at Montana State University, with local support supplementing NSF funds, has made what many experts consider to be the paleontological find of the century. His discovery and analyses of dinosaur eggs and embryos found in Choteau, Montana are adding much to our understanding of these prehistoric animals.
- *Lothar Schaeffer* at the University of Arkansas has been developing new instrumentation and techniques to study chemical structures. Work begun with NSF funds has continued with \$250,000 from the Department of Defense's equipment program.
- Scientists at the University of Maine at Orono and the Bigelow Laboratory for Ocean Sciences have been working together to learn more about the physical and biological properties of the Gulf of Maine and its associated estuarine system.
- Seven EPSCoR investigators at Montana State University have been involved in a program funded by the National Institutes of Health, in which American Indian undergraduates work as research apprentices on NSF-aided projects.

Women in Research

Since 1982, the Foundation has encouraged the participation of women in science and engineering by awards for visiting professorships in U.S. academic institutions. Along with their NSF-supported research, visiting professors conduct lectures, counseling sessions, and other work to encourage female students to pursue careers like theirs.

In 1984, NSF made 29 of these awards, totaling \$2.09 million. The grants, ranging from \$31,900 to \$113,900, went to applicants from 23 states. Among those receiving awards:

- *Molly F. Miller*, a geologist from Vanderbilt University, is spending a year at Rensselaer Polytechnic Institute (RPI). She is studying the Catskill delta complex, a wedge of sedimentary rocks dating to the De-

vonian Period, some 380 million years old. Her research will yield a history of these rocks and the mountain-building processes they reflect. In addition, she teaches a paleoecology course and seminar at RPI, lectures at Skidmore College and Smith College, and discusses careers in geology with high school and college students.

- *Janet Randall* is a biologist from Central Missouri State University. During her year at Cornell, she is doing comparative laboratory and field studies on two species of kangaroo rats. Her research will give us new information about olfactory communication in small mammals, add to our understanding of unique forms of communication in natural communities of desert animals, and help interpret desert ecosystems in general. She also teaches a course in animal communication and lectures on psychology and behavior.
- *Sun-Yung Alice Chang*, a mathematician from UCLA, is doing research in harmonic analysis at the California Institute of Technology and investigating applications of her work in mathematical physics. She is also giving seminars in analysis and joining with students in the activities of Caltech's Math Club.
- *Patty Wisian-Neilson*, a chemist from Southern Methodist University, is doing research and teaching at the Massachusetts Institute of Technology. Her research is on ferrocenyl-substituted polyphosphazenes, a novel type of inorganic polymer. This polymer is expected to have useful thermal, mechanical, or electrical properties. She also is giving graduate and undergraduate seminars, collaborating in a new course on inorganic polymers, directing undergraduate research, and participating in a "Women in Chemistry" symposium for undergraduate and graduate women.
- *Evelyn Fox Keller's* work at her home institution, Boston Univer-

sity, bridges mathematics and the humanities. She too is spending a year at MIT, doing research on the relationships between gender, ideology, and science. In addition, she gives an introductory course on those relationships for undergraduates and a workshop for graduate students and faculty.



Visiting Professors. Under NSF's Visiting Professorships for Women program, mathematician-computer scientist Lenore Blum (top) did research at the City University of New York on randomness, complexity, and finite dynamics. At Texas Tech, Karen R. Hitchcock investigated key signals in determining a cell's fate. (Photo of Blum by Walter S. Silver)



Preparing Instrumentation. Kristina B. Katsaros, a specialist in air-sea interaction processes, prepares instrumentation for an international experiment in humidity exchange over the sea. An associate professor of atmospheric sciences at the University of Washington, she spent 1984 as a visiting professor at the Naval Postgraduate School in Monterey, California.

Insect-Plant Interaction. Diane W. Davidson, a University of Utah biologist, spent the 1983-84 academic year at Princeton University. An NSF award afforded her an intensive introduction to tropical ecology and enabled her to acquire expertise and contacts for further research on insect-plant interaction.



Minorities in Research

NSF tries to increase the number and research capability of minority scientists and engineers through awards to individuals and support to institutions with large minority enrollments.

Minority Research Initiation (MRI) grants aid scientists and engineers who are members of ethnic and racial minorities. The grants support work by faculty who have not previously received federal research support. In FY 1984, for example:

- *John Ashe* (University of California, Riverside) studied the physiological basis by which organisms adapt to their environment, especially through learning. Results from his experiments show that associated plasticity, a nervous system variation, involves a change in the transmission of nervous impulses by synapses (the points where those impulses pass from one neuron to another).
- *Donald St. Mary* (University of Massachusetts, Amherst) generalized a scalar equation to nonlinear differential systems. This mathematics research represented the first efforts to formulate the Bohl transformation-differential equation in more than one dimension.
- *Alexander Cruz* (University of Colorado, Boulder) collected and analyzed a large body of data on the ecology and evolution of avian brood parasitism, in which one type of bird uses the nests of other birds to hatch its eggs. Cruz studied shiny cowbirds in the recent extension of their range into the Caribbean region. While using the nests of other birds for brooding, these cowbirds often destroy eggs of the host. Among other things, this research suggests that aggressive reactions to the presence of the cowbirds by host species vary markedly.
- *Curtis Parker* (Morehouse School of Medicine) assessed the effects of tetrayonic acid on cartilage cell differentiation during the early stages

of a chicken's growth. He has developed a simplified, workable, and shell-less culture system that allows total observation of the chick embryo from any angle. Parker also has increased the growth and survival of chick embryos by culturing them in an environment where the oxygen level is 40 percent.

- *Jaime Díaz* (University of Washington) perfected a technique of rearing rat pups in total isolation from their mothers, using a surgically implanted intragastric device to feed the young. This procedure, which allows several animals to be reared simultaneously, has also generated unique new data for addressing key issues of brain development—notably the effects of inadequate early nutrition.

Grants for Research Improvement in Minority Institutions (RIMI) strengthen the research capabilities of colleges and

- Solid-state engineers at Howard University completed the installation of a molecular beam epitaxial system. This system is being used, in part, to try various research techniques that may improve certain high-performance diodes (electron tubes).
- Researchers in the chemical physics laboratory at Jackson State University collected and analyzed data from several electron transfer reactions in thin films. The results of these studies will help scientists understand interstellar clouds and planetary atmospheres.
- Mathematical researchers at Atlanta University perfected a technique for solving nonsingular integral equations from singular ones. These numerical methods will be used to formulate mathematical models and computer simulation techniques for research on dynamic systems.



MRI Awardee. Dr. Sigrid R. McAfee is shown with two students in her electrical engineering laboratory at Rutgers University.

universities with substantial numbers of minority students. The awards also respond to President Reagan's Executive Order 12320, which calls for support of historically Black colleges and universities. The following research activities were among those aided by RIMI funds in 1984:

Ethics and Values

The Foundation, often jointly with other federal agencies, supports research on the ethical problems and value conflicts associated with scientific, engineering, and technical activities. This research contributes to informed public



University of Puerto Rico-Mayaguez. Faculty and students at this institution are using a gas chromatograph and auxiliary equipment that are part of the Chemistry Research Instrumentation Laboratory. The lab was established with a RIMI grant.

and professional discussion of important social issues. In 1984, NSF made 25 awards averaging \$39,600 each, for Ethics and Values in Science and Technology (the EVIST program). Other federal agencies—mainly the National Endowment for the Humanities—contributed an additional \$267,668 to support 11 of the awards; other NSF programs contributed \$58,222.

The importance of short-term versus long-term benefits and risks is one example of an important ethical and social issue. EVIST grants have supported several projects that examine this issue and its implications for science and technology endeavors.

A project on intergenerational ethics and national energy policy examined economists' use of so-called social discount rates in assessing policy choices. These rates discount effects on future generations by setting an arbitrarily reduced percentage of probable risks or costs over time; thus a negative effect in the distant future counts for less than if it happened now. The study concluded that devaluing the interests of future energy users in this way is ethically unacceptable, and decisions based on these rates need reconsideration. This and other

findings are reported in *Energy and the Future*, edited by Douglas MacLean and Peter Brown (1983, Rowman and Littlefield).

Changing institutional arrangements also affect the relative importance of short- and long-term interests in key scientific decisions. Preliminary results from several EVIST projects indicate that new developments in biotechnology—and in the institutional arrangements evolving with this new technique—may give more priority to short-term rather than long-range goals in the area of agricultural research.

Investigators at the University of Kentucky reported in May 1984 on 90 interviews with agricultural researchers and research administrators. Their findings confirmed that those using recombinant DNA techniques for agricultural pur-

poses are being pushed to deliver products quickly, rather than pursue longer-term research goals. The next stage of this project will examine the ethical implications of this phenomenon.

Other Government Levels

The Foundation helps state and local governments develop scientific and technical resources that will meet their needs. Two examples of current efforts are:

1. The National Governors' Association and the National Conference of State Legislatures have aided policy officials in state executive and legislative branches. This help was part of the NSF-supported State Science, Engineering, and Technology (SSET) program. Activities included collecting and sharing information and developing background papers and analyses. Assessments of SSET projects in 15 states have documented many successful activities.
2. In 1979, NSF gave a three-year continuing award, totaling \$175,000, to set up a Florida group that would help local governments address technology problems. When the award expired in late 1982, a nonprofit corporation, the Florida Innovation Group (FIG), had been created. Twenty Florida communities are involved in FIG, which is now totally supported by their dues and by help from the private sector. In April 1984, FIG directors replicated this experience by launching, without federal support, a Virginia Innovation Group that involved a dozen city and county managers in that state.

International Scientific Cooperative Activities

The Foundation manages cross-disciplinary programs with about 30 other countries under bilateral agree-

ments. Except for India and Pakistan, where expenses are met with U.S.-owned local currencies (special foreign

currency), program costs are shared by the United States and the other countries.

NSF's bilateral partners in cooperative research fall into three groups: (1) the industrial, market-economy countries of western Europe, East Asia, and Oceania; (2) China and the centrally controlled, industrial countries of eastern Europe; and (3) the less industrial countries of Africa, Asia, and Latin America.

International exchange of scientific knowledge with government help occurs in several ways. Formal arrangements often allow scientists and engineers to work in the national laboratories of another country. Governments that recognize the value of building strong personal ties among tomorrow's senior scientists, whatever their nationality, try to help today's younger researchers surmount the difficulties of spending substantial time in research and study abroad. International cooperation and exchange also result when the heavy expense of certain research equipment and facilities leads countries to share their costs and use.

The Foundation helps U.S. investigators to take part in cooperative international research projects. With their foreign counterparts, they develop the projects and share responsibility for the work. Each country shares the costs and the benefits. The following examples illustrate that mutuality of benefit.

Remote Sensing in Arid Lands

E. M. El-Shazli of Egypt's Remote Sensing Center and M. A. Abdel Hady of the University of Oklahoma have cooperated in engineering research aimed at managing natural resources in arid lands. The key research topics in Egypt—environmental monitoring, resources planning, crop and industrial assessment, surveying mineral resources—mirror those in many other countries, including the United States. All these problems can be approached through remote sensing technology, which links high-altitude photography with advanced analytical techniques. The results are useful to planners and policy makers.

Ten years of research and development have produced the Remote Sensing Center in Cairo, one of the world's most advanced facilities of its kind. It includes a data processing laboratory, aircraft imaging systems and other airborne equipment for remote sensing, a large color photo lab, and a spectral measurement lab. The project was partly funded by NSF, which supported the participation of U.S. scientists and engineers. The government of Egypt and the U.S. Agency for International Development were the other main contributors.

At this writing, the project has fully trained 65 specialists and has given briefer training to some 300 persons representing 40 countries. The center has developed the capability to produce Landsat images of Egypt and has published such maps covering the Sinai—useful information to scientists and engineers of all countries. The project has advanced U.S. research goals in a number of instrumentation and other design projects. For Egypt, benefits have ranged from rapid detection of crop diseases to an understanding of how 1981 earthquakes were linked to the seepage of Nile water from the Aswan High Dam Reservoir.

Control of Reproductive Cells

To understand reproduction, we must know how sex cells develop. We have learned that the maturation of eggs and sperm while they are still in the ovaries and testes can be dramatically influenced by certain chemical substances. Some of

these chemicals are normally found in the body of the organism that produces the sex cells.

The late Haruo Katani and his colleagues at Japan's Okazaki University were internationally known for discoveries about the influences of chemicals upon egg-cell maturation. Last year this research group sought to extend its efforts by searching for genetic mechanisms that the body might use to control production of these chemical regulators. In the United States, Samuel Koide of The Population Council was also interested in the mechanics of egg maturation and needed to learn about the methods used by the Japanese group. In return, he was able to offer certain genetic techniques needed by his foreign colleagues.

Together the U.S. and Japanese scientists established the powerful effect of one important substance—serotonin—on the release of eggs and sperm. Serotonin is naturally produced by nerve cells; in the nervous system it is thought to act as a chemical messenger.

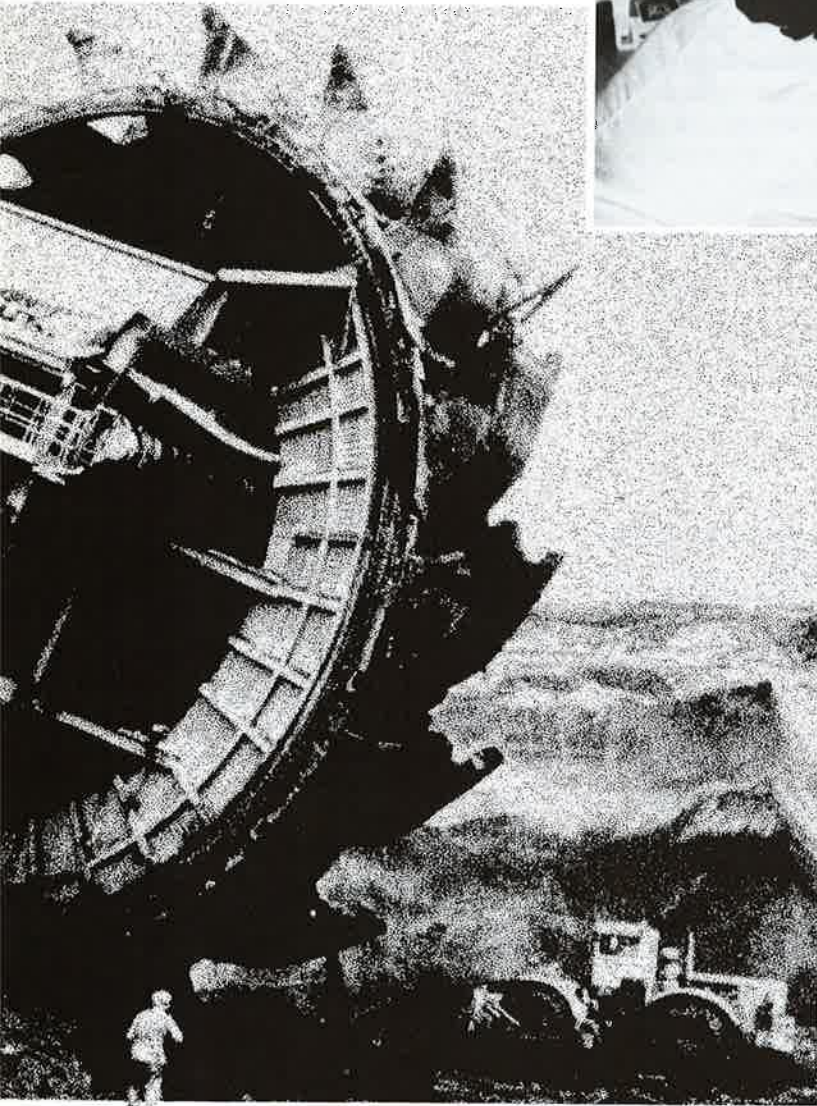
For their experiments the scientists selected a common surf clam; studies of its reproductive cells had already yielded background information that they needed. They used serotonin to stimulate the clams to release their egg and sperm cells. These cells were found to be normal; when brought together in a dish of sea water, the sperm fertilized the eggs and the resulting embryos developed into normal, swimming larvae. The project, active throughout FY 1984, yielded valuable information about the way genetics and body chemistry control reproduction.

Policy Research and Analysis

The Foundation has a statutory responsibility to provide information that other federal agencies can use to develop science policy. To keep this knowledge base current and useful to executives, NSF

supports policy research on science and technology issues of national concern. These include: impacts of federal and foreign-government policies on U.S. science and industry; relationships among

Joint Work. U.S. scientists and engineers engage in cooperative research with their colleagues in other countries for many reasons — the most important being the access that joint projects provide to expert scientists and unique research facilities abroad. These photos reflect cooperative projects in China, the Federal Republic of Germany, India and Venezuela.



government policies and specific technologies, industries, and natural resources; and improving policy analysis methods.

In FY 1984 studies focused on such areas as the impact of new tax laws on industrial research and development; the possibilities of climatic changes caused by carbon dioxide; public attitudes toward the risks we face in modern life; government support of high technology in several industrial nations; and methods to measure the accomplishments of basic research. An example of one policy research study follows.

Automobile Recycling

Recovery of the large quantities of materials consumed by automobile production could yield an important resource and reduce waste-disposal problems. To address this problem, the American Society of Mechanical Engineers has studied the impact on the automobile recycling industry of substitute materials such as aluminum and plastics.

Since the 1970s, the desire for greater fuel efficiency has forced manufacturers to reduce the weight of automobiles, in part by substituting lightweight materials for heavy ones. Over the past decade, the weight of the average automobile has decreased by one-third as manufacturers increased the content of aluminum and plastics or polymer materials and decreased the use of stainless and carbon steel.

Greater use of aluminum in cars may benefit recycling; the potential supply of automotive aluminum scrap may eventually increase to three times its current level, making aluminum the most valuable scrap component by the late 1990s. Some advancements in recycling technology may be needed to keep pace with this growth and to exploit aluminum reuse fully.

More use of plastics also has recycling implications. Ideally, plastics should be separated from scrap for reprocessing, but separation by the traditional method of pyrolysis may no longer be environmentally acceptable. The growing plastic

content of automobiles generates air pollutants, and alternative separation methods may have to be developed.

In their NSF-supported study, the engineering researchers concluded that despite adjustments which the automotive recycling industry will need to make because of substitute materials, those

changes are unlikely to affect the industry adversely or greatly change the rate of vehicle abandonment. The growing use of high-strength steel alloys probably will not hinder scrap-iron recycling, and the biggest challenge faced by the recyclers is separation and reuse of the growing quantities of plastics.

Science Resources Studies

The Foundation conducts many surveys and analyses of the nation's scientific and technical resources. The result is an array of NSF publications that help officials in federal, state, and local governments, educational institutions, and industry develop and evaluate science & technology policy and allocate resources effectively.

In FY 1984, the Foundation issued some 40 reports and summaries that provided comprehensive national overviews of the supply and usage rates of scientific and technological personnel, research and development funds, and other resources. Some projects of special interest follow.

Postcensal Survey

Early in each decade, the Bureau of Census conducts for the Foundation a special survey of scientists and engineers identified in the decennial census. This *Postcensal Survey*, started in 1982 and completed during 1984, will serve as the benchmark for calibrating estimates of the employment and other characteristics of U.S. scientists and engineers during the 1980s.

Comparison with a similar survey 10 years before shows that employment of scientists and engineers increased by 50 percent between 1972 and 1982. This was about two and one-half times the increase in total employment over the same period. Employment of female scientists and engineers increased by over

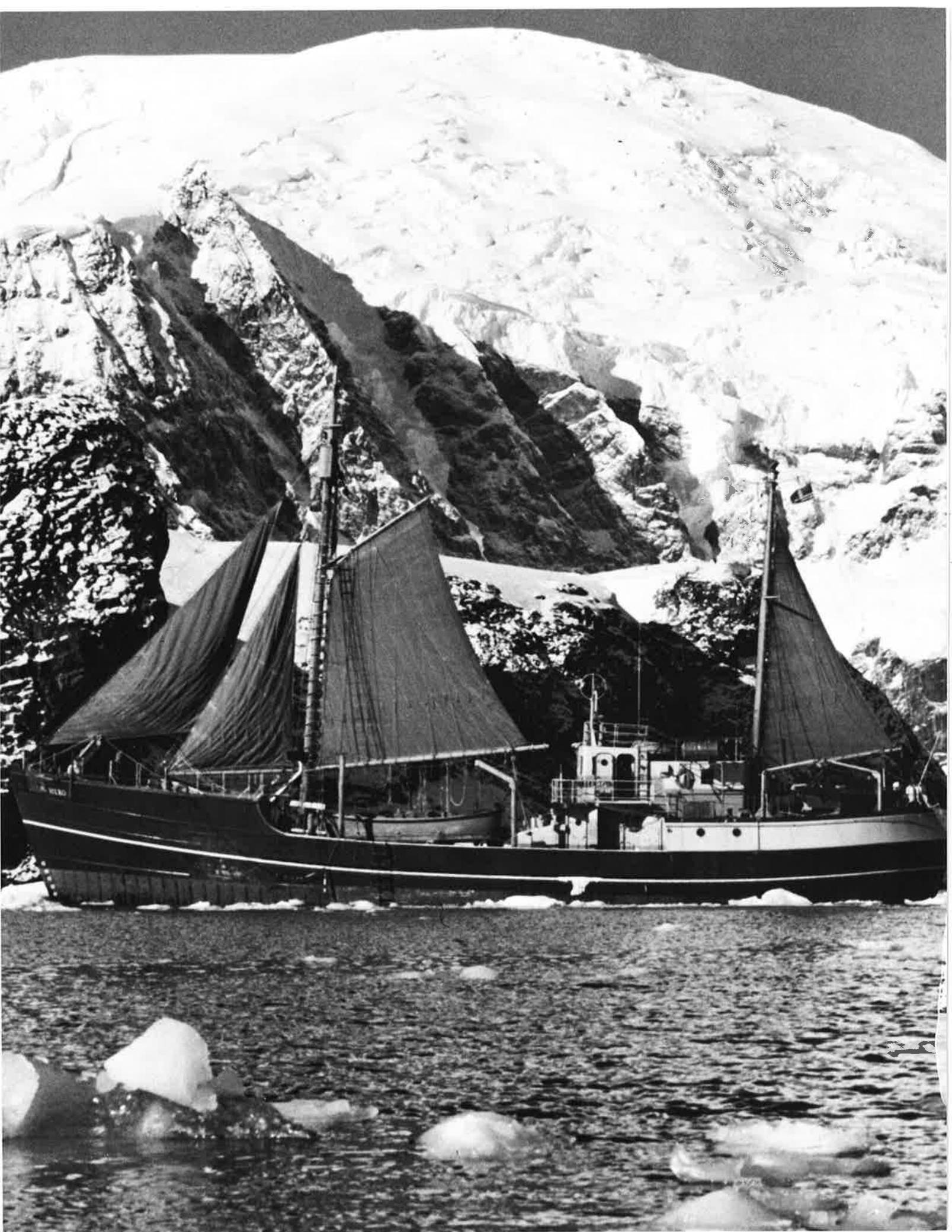
200 percent; that of males, 25 percent. The number of Black scientists and engineers went up by about 85 percent, twice the increase for whites. Despite these boosts, both females and minorities are still underrepresented in the scientific and engineering professions.

Equipment Survey

In response to a congressional mandate, the Foundation has begun to develop quantitative indicators of the condition of university research instrumentation. In 1983 a three-year study, the first of its kind, started to examine the stock, usage, and requirements for research equipment in selected fields of science and engineering. Phase I, completed during 1983, covered engineering and the physical and computer sciences. Phase II, completed in 1984, covered agricultural, biological, environmental, and medical sciences.

The surveys were based on a nationally representative sample of science and engineering departments at 43 major research universities, selected from among the 160 largest academic research and development (R&D) performers. Information came from a subsample of instruments costing at least \$10,000.

In the three fields surveyed in 1983, university researchers classified about one-fourth of their research equipment as obsolete and no longer in use. Based on the researchers' estimates, the purchase costs of systems in use in 1982 totaled



Antarctic Research

7

The coldest continent and its surroundings serve as a natural laboratory for studying solar-terrestrial interactions, atmospheric and oceanic processes, present and former climates, geologic history, and the adaptations of life forms to extreme environments. Basic research also is outlining Antarctica's potential for renewable and nonrenewable resources, and it gives us key information for managing resources and protecting the environment.

The United States maintains an active and influential presence in Antarctica, supporting the Antarctic Treaty and promoting scientific endeavors in the region. Under a special budget appropriation, NSF manages and funds the U.S. activities in Antarctica, including logistics and support provided by contractors and other federal agencies. University scientists—grantees of the Foundation—do most of the research. Fifteen other nations also sent expeditions to the region during 1984.

During the 1983-84 austral summer and the 1984 austral winter, U.S. scientists performed 93 research projects in the antarctic. Disciplines represented were astronomy, upper-atmosphere

physics, meteorology, glaciology, geology and geophysics (oceanic and terrestrial), physical and chemical oceanography, marine and terrestrial biology, and medical research.

Research Highlights

Table 7
U.S. Antarctic Program
Fiscal Year 1984
(Dollars in Millions)

	Fiscal Year 1984	
	Number of Awards	Amount
U.S. Antarctic Research Program	140	\$ 10.43
Operations Support Program	13	91.96
Total	153	\$102.39

SOURCE: Fiscal Year 1986 Budget to Congress-Justification of Estimates of Appropriations (Quantitative Program Data Tables) and NSF accounting records.

Biotic Production in Ice-Edge Zone

Sea ice covers 11 to 13 percent of the world ocean. Around Antarctica it grows each winter to 8 million square miles—more than twice the area of the United States. Forty-one scientists on the research ship *Melville* and the icebreaker *Westwind* have studied the physics, chemistry, and biology of the sea-ice margin in the northwestern Weddell Sea. They addressed these two hypotheses: (1) the ice-edge zone is associated with a major oceanic front where biotic productivity is high, and (2) the seasonal advance and retreat of the ice margin strongly influence the natural history of organisms in the region.

By analyzing temperature, salinity, and other factors, physical oceanographers found two features likely to influence biomass production in the region they were studying: a hydrographic front near 59 degrees South and a low-salinity area, presumably generated by ice melt, extending about 200 kilometers north of the ice edge.

The marginal ice zone was 150 to 200 kilometers wide. It had some open water, which generally diminished as one moved south. Even when the scientists were working in Antarctica's midsummer, the oceanographic stations with continuous pack-ice cover had "winter water" conditions: low temperatures (-1.8 degrees centigrade) and abundant nutrients, but little chlorophyll or bacterial biomass. Although these "winter waters" were very clear, the sea ice and its snow cover greatly restricted penetration of sunlight; the resulting darkness probably accounts for the low levels of phytoplankton biomass that the researchers observed.

Biological data taken across the ice-edge zone revealed a distinct pattern of distribution at all trophic levels, with organisms most abundant and most active at the northern limit of the marginal ice zone or in open ocean just north of the ice edge. Biomass and activity diminished toward the south, as the ice cover became more complete, and toward the north in

the ice-free ocean. This pattern was obvious for phytoplankton and bacterioplankton—foundations of the region's food web. They convert dissolved nutrients into protein-rich particles that become the food for higher organisms such as zooplankton, including the shrimplike krill. The latter are in turn eaten by fishes, birds, and marine mammals.

As a result of their cruises, scientists are beginning to appreciate more acutely the physical, chemical, and biological factors that lead to high productivity around sea ice. The communities of algae, bacteria, and protozoans depend on one another and on the physical and

High-Latitude Origin of Species

Fossils recovered from Seymour Island, Antarctica have been found to predate their descendants in the middle and lower latitudes by as much as 40 million years. This finding, along with a 1983 report of similar results from the arctic, suggests that the high-latitude regions have been more important in the development of Cenozoic fauna and flora than we realized before.

In early 1984, 14 scientists representing five institutions worked at Seymour Island to continue fossil searches made in



Seymour Island fossils. Many scientifically significant fossils were found on Seymour Island, an area off the eastern tip of the Antarctic Peninsula. These fossils of the Eocene decapod *Lyreidus antarcticus* were collected there in such large quantities that a detailed study of the comparative anatomy of the species is now possible.

chemical setting. Zooplankton such as mysids and krill, normally open-ocean animals, appear to use labyrinths in decaying ice and waters beneath the ice as feeding sites and as refuges from predators. The ice floes have distinct phases of growth, movement, and decay. Each phase is physically distinct and includes differential development of trophic levels, from bacteria to marine mammals.

1982 and 1975. The island, which shows almost continuous exposure of Cretaceous and early Tertiary rocks, once again yielded new discoveries nearly every day. Among the Eocene vertebrate fossils that the team collected were fishes, birds, whales, and the first terrestrial mammal from Antarctica (reported in the Foundation's FY 1982 annual report). Of particular significance during the 1984

work was the collection of nearly all the invertebrate Eocene phyla.

Purdue University's William Zinsmeister, who coordinated the expeditions, calls Seymour Island the Rosetta Stone for paleontological interpretation of the Southern Hemisphere. The fossil sequence contains a nearly complete record from the final breakup of Gondwana to the development of glacial conditions during the early Neogene.

Because of the island's intermediate location along the southern margin of the Pacific, the data provide new insight into biogeographic history. They testify to the importance of the high latitudes in the development of midlatitude species. The sudden appearance of plant and animal groups in the midlatitude geologic record may reflect major episodes of dispersal from the high-latitude regions.

Antarctic Volcanos: Surprise Eruptions and a First Visit

In late 1984, several major—and unexpected—eruptions jolted Mt. Erebus, the world's southernmost active volcano. One of the incidents, the largest since the antarctic volcano was discovered in 1841, threw incandescent lava as high as 600 meters above the Erebus crater rim. Also sighted were mushroom-cloud plumes and a black ash covering the summit's northwest slopes.

Despite this dramatic display, the research team studying it believes there is no danger of Mt. Erebus becoming another violently explosive volcano like Mount St. Helens. The eruptions are, however, key scientific events.

At 3,794 meters, Mt. Erebus is the largest and most studied of the continent's five active volcanos. It dominates the landscape visible from McMurdo Station, and the Erebus crater harbors one of only two active lava lakes in the world.

Since 1980, a geophysical team from the United States, Japan, and New Zealand has monitored the mountain's seismic phenomena. Philip R. Kyle, at the New Mexico Institute of Mining and Technology, heads the team, which has

Desolate spot. Lovill Bluff is at the base of Mount Siple, an antarctic volcano on Siple Island. No one had ever set foot on the volcano until early 1984, when researchers gathered geological data and laid the groundwork for mapping.



installed permanent seismic stations on the volcano. In late 1982 they observed an unusual number of small earthquakes at Mt. Erebus. At that time, they thought there was little chance of a violent eruption because no excess pressure seemed to be building within the volcano.

Until mid-September 1984, the Mt. Erebus team had recorded no notable seismic activity all year. But at that time frequent minor earthquakes were felt at McMurdo Station, some 40 kilometers from the crater. At the South Pole, more than 1,600 kilometers away, a sensitive instrument called a gravimeter also detected the quakes. Even so, scientists know from looking at older rocks on the mountain that Erebus has not had a history of violent eruptions, and they assume that situation will continue.

The scientists did expect to see some future lava flows down the mountain, and they suspected the existence of a geyser at one eruption site. To find out if this was so—and what caused the volcano's unpredictable show of force—they headed south to the coldest continent in late October. There they began to collect and chemically analyze magma (molten rock) and gas samples from the fall 1984 ejections.

Another antarctic volcano, Mt. Siple, has been known since 1940, when U.S. aviators spotted it from their planes. Some 3,110 meters tall, it is one of the largest volcanos in Antarctica, dominating the northwestern part of Siple Island.

Until 22 February 1984, no one had set foot on Mt. Siple. On that day, the following events took place:

- Geologists from the University of Colorado gathered information about the region's past volcanic activity.
- Glacial geologists from the University of Maine examined soils and rocks and collected samples to evaluate the glacial history of the region.
- A U.S. Geological Survey team established geodetic control points for mapping.
- A Coast Guard photographer made detailed geological photographs from a helicopter.

This short visit was made possible by a brief respite from the region's notorious weather, during a passage of the Coast Guard icebreaker *Polar Sea* from McMurdo Station to Palmer Station.

Other Activities



NSF Planning and Evaluation

NSF regularly develops, collects, and uses information to set priorities, plan programs, identify staff and support needs, and deal with major program-related issues. To supplement analyses done by its own staff, NSF also supports a few extramural activities. Highlights of 1984 work include:

- Core support for the Committee on Science, Engineering, and Public Policy (COSEPUP), a joint effort of the National Academy of Sciences, the National Academy of Engineering, and the National Institute of Medicine.
- A study of patterns of collective industrial research.
- Exploratory studies of the role of industrial support in faculty research strategies.
- An assessment of NSF's *Five Year Outlook* volumes, which was used in hearings before the U.S. House Science, Research, and Technology Subcommittee on 24 February 1984.
- A look at trends in the baccalaureate histories of Ph.D.s in selected fields of science and engineering.

Issues in the funding and performance of scientific and engineering activities are of continuing concern to NSF. Examples of such issues are the allocation of support among research areas; how science and engineering relate to achieving national goals; better ways to support

science and engineering; the economic and social consequences of that support; ways to develop the nation's technology potential; opportunities for, and constraints on, developing technical fields.

An important planning function is staff support to certain committees and groups of the National Science Board, NSF's policy-making body. These include the Planning and Policy Committee, the Committee on Minorities and Women in Science, the Committee on International Science, and working groups dealing with such issues as engineering research and education; precollege education in mathematics, science, and technology; university-industry research relationships; and planning capital facilities for academic research and development.

Special science and technology reports are also developed and coordinated by NSF planning staff, with the aid of outside experts. In FY 1984 these included:

- *Research Briefings* on opportunities in nine selected areas of science and engineering, prepared by COSEPUP in consultation with NSF and the White House Office of Science and Technology Policy.
- A chapter on "Advances in Science" in *Science Indicators 1982*, sent to the President in November 1983.
- The *Annual Science and Technology Report to the Congress: 1982*, sent to the U.S. Congress in October 1983, prepared by the Office of Science and Technology Policy in collaboration with NSF.

Evaluation studies brief the NSF Director on the results of major Foundation programs and the integrity of the agency's process for making financial awards. Such studies form the basis of his oversight responsibilities in these areas. In 1984, for example, the National Academy of Sciences finished an evaluation of NSF's chemistry division (a study suggested by the U.S. Senate Appropriations Committee). The Academy also did its annual study of "The Fairness of the NSF Award Decision Process."

Alan T. Waterman Award

This NSF award recognizes an outstanding young person in the forefront of science. In addition to a medal, the recipient receives a grant of up to \$50,000 per year for a maximum of three years. Candidates for the award must be U.S. citizens 35 years of age or younger, or not more than five years beyond receipt of the doctoral degree on December 31 of the year they are nominated. Emphasis is on a candidate's record of completed, high-quality, innovative research—work that shows outstanding capability and exceptional promise for making significant achievements in the future.

Nine persons have received this award: three mathematicians, two physicists, one paleobiologist, one chemist, and two biologists. The ninth recipient, Harvey M. Friedman of Ohio State University, was honored in 1984 for constructing some surprising examples of logically undecidable mathematical propositions, the answers to which cannot be given with certainty.

Friedman has made fundamental contributions to virtually all branches of mathematical logic. He is the leading spokesman for the unification of such logic and has assumed a commanding role in harnessing its powerful technical machinery to prove foundational results. These results are of general scientific interest and often have striking philosophical implications. Combining both technical skill and profound abstract conceptual concerns, he has shown by one example after another that research on the foundations of logic, extending a 200-year-old tradition, is intellectually fruitful and highly relevant to contemporary mathematical and technological concerns.

Most notable among Friedman's contributions has been his discovery of mathematically interesting, undecidable mathematical propositions. In the 1930s the late Kurt Gödel startled the scientific world by constructing a mathematical



Harvey M. Friedman. In 1984 the Ohio State University mathematician was presented the NSF's ninth Alan T. Waterman Award for constructing some surprising examples of logically undecidable mathematical propositions.

statement and showing that this statement had no proof or disproof. The statement itself was exceedingly complicated, contrived, and of little independent mathematical interest. But since then, mathematicians have eagerly sought undecidable statements of natural intellectual appeal. Over the years, slow progress has been made, but Friedman has found natural statements about combinatorial graphs (collections of line segments meeting at junction points) and demonstrated that these statements also cannot be proved or disproved.

The concepts and methods developed by Friedman are expected to provide a framework for demonstrating that some famous unproved mathematical conjectures of a concrete nature are actually undecidable. His ideas and techniques also may contribute significantly to the study of algorithm theory and other areas of computer science.

Appendix A

National Science Board Members and NSF Staff (Fiscal Year 1984)

NATIONAL SCIENCE BOARD

Terms Expire May 10, 1986

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 Peter D. Lax, Professor of Mathematics, Courant Institute of Mathematical Sciences, New York University, New York, New York
 Homer A. Neal, Provost, State University of New York at Stony Brook, Stony Brook, New York
 Mary Jane Osborn, Professor and Head, Department of Microbiology, University of Connecticut Health Center, Farmington, Connecticut
 Donald B. Rice, Jr., President, Rand Corporation, Santa Monica, California
 Stuart A. Rice, Dean of the Division of Physical Sciences, The James Franck Institute, University of Chicago, Chicago, Illinois

Terms Expire May 10, 1988

Robert F. Gilkeson, Chairman of the Executive Committee, Philadelphia Electric Company, Philadelphia, Pennsylvania
 Charles E. Hess, Dean, College of Agricultural and Environmental Sciences, University of California, Davis, California
 William F. Miller, President and Chief Executive Officer, SRI International, Menlo Park, California
 John H. Moore, Associate Director and Senior Fellow, The Hoover Institution, Stanford University, Stanford, California
 William A. Nierenberg, Director, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California
 Norman C. Rasmussen, Professor of Nuclear Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts
 Roland W. Schmitt, Senior Vice President, Corporate Research and Development, General Electric Company, Schenectady, New York

(One Vacancy)

Terms Expire May 10, 1990

Rita R. Colwell, Vice President for Academic Affairs and Professor of Microbiology, University of Maryland, Adelphi, Maryland
 (Four Vacancies; three nominees not yet confirmed at this writing)

Member Ex Officio

Erich Bloch (Chairman, Executive Committee), Director, National Science Foundation, Washington, D.C.

Margaret L. Windus, Executive Officer, National Science Board, National Science Foundation, Washington, D.C.

NATIONAL SCIENCE FOUNDATION STAFF (as of September 30, 1984)

Director, Erich Bloch (effective 9-4-84; previous Director, Edward A. Knapp)
 Deputy Director (Acting), Richard S. Nicholson
 Staff Director, Richard S. Nicholson
 Director, Office of Equal Opportunity (Acting), Dimas Chavez
 General Counsel, Charles Herz
 Director, Office of Legislative and Public Affairs, Raymond E. Bye
 Controller, Edward F. Hayes
 Director, Office of Advanced Scientific Computing, John W. Connolly
 Director, Office of Audit and Oversight, Jerome H. Fregeau
 Director, Office of Small Business Research and Development, William B. Cole, Jr.
 Director, Office of Small and Disadvantaged Business Utilization, William B. Cole, Jr.
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 Director, Division of Mechanical Engineering and Applied Mechanics, John A. Weese
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- Director, Division of Personnel and Management*, Geoffrey M. Fenstermacher
- Director, Division of Administrative Services*, Troy T. Robinson

Appendix B

Financial Report for Fiscal Year 1984 *(in thousands of dollars)*

Research and Related Activities Appropriation

Fund Availability

Fiscal year 1984 appropriation	\$1,142,260	
Unobligated balance available, start of year	704	
Adjustments to prior year accounts	3,564	
Fiscal year 1984 availability		<u>\$1,146,528</u>

Obligations

Astronomical, Atmospheric, Earth, and Ocean Sciences:

Astronomical Sciences	\$77,175	
Atmospheric Sciences	88,023	
Earth Sciences	41,309	
Ocean Sciences	114,276	
Arctic Research Program	7,266	
Subtotal, Astronomical, Atmospheric, Earth, and Ocean Sciences		<u>\$328,049</u>

Biological, Behavioral, and Social Sciences:

Molecular Biosciences	\$53,949	
Cellular Biosciences	47,129	
Biotic Systems and Resources	52,769	
Behavioral and Neural Sciences	38,093	
Social and Economic Sciences	24,500	
Information Science and Technology	6,152	
Subtotal, Biological, Behavioral, and Social Sciences		<u>\$222,592</u>

Engineering:

Electrical, Computer, and Systems Engineering	\$35,452	
Chemical and Process Engineering	25,993	
Civil and Environmental Engineering	33,103	
Mechanical Engineering and Applied Mechanics	23,809	
Subtotal, Engineering		<u>\$118,357</u>

Mathematical and Physical Sciences:

Mathematical Sciences	\$41,130	
Computer Research	33,635	
Physics	104,107	
Chemistry	79,225	
Materials Research	96,049	
Subtotal, Mathematical and Physical Sciences		<u>\$354,146</u>

Scientific, Technological, and International Affairs:	
Industrial Science and Technological Innovation	\$18,028
International Cooperative Scientific Activities	12,936
Policy Research and Analysis	4,584
Science Resources Studies	4,178
Research Initiation and Improvement	9,038
Subtotal, Scientific, Technological, and International Affairs	<u>\$48,764</u>
Advanced Scientific Computing	\$6,009
Program Development and Management	\$66,257
Subtotal, obligations	<u>\$1,144,174</u>
Unobligated balance available, end of year	<u>\$2,053</u>
Unobligated balance lapsing	<u>\$301</u>
Total, fiscal year 1984 availability for Research and Related Activities	<u><u>\$1,146,528</u></u>

U.S. Antarctic Program Activities Appropriation

Fund Availability

Fiscal year 1984 availability (appropriation)	<u>\$102,456</u>
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Obligations

U.S. Antarctic Research	\$10,433
Operations Support Program	91,955
Subtotal, obligations	<u>\$102,388</u>
Unobligated balance available, end of year	<u>\$68</u>
Total, fiscal year 1984 availability for U.S. Antarctic Program Activities	<u><u>\$102,456</u></u>

Science and Engineering Education Activities Appropriation

Fund Availability

Fiscal year 1984 appropriation	\$75,000
Unobligated balance available, start of year	13,913
Adjustments to prior year accounts	60
Fiscal year 1984 availability	<u>\$88,973</u>

Obligations

Graduate Research Fellowships	\$20,311
Precollege Science and Mathematics Education	37,132
Subtotal, obligations	<u>\$57,443</u>
Unobligated balance available, end of year	<u>\$31,450</u>
Unobligated balance lapsing	<u>\$80</u>
Total, fiscal year 1984 availability for Science and Engineering Education Activities	<u><u>\$88,973</u></u>

Special Foreign Currency Appropriation**Fund Availability**

Fiscal year 1984 appropriation	\$2,900	
Unobligated balance available, start of year	14	
Adjustments to prior year accounts	79	
	<hr/>	
Fiscal year 1984 availability		<u>\$2,993</u>

Obligations

Special Foreign Currency	\$2,911	
Unobligated balance available, end of year	37	
Unobligated balance lapsing	45	
	<hr/>	
Total, fiscal year 1984 availability for Special Foreign Currency Program		<u>\$2,993</u>

Trust Funds/Donations**Fund Availability**

Unobligated balance available, start of year	\$3,805	
Receipts from nonfederal sources	5,675	
Adjustments to prior year accounts	129	
	<hr/>	
Fiscal year 1984 availability		<u>\$9,609</u>

Obligations

Ocean Drilling Programs	\$6,678	
Gifts and Donations	78	
U.S.-Spain Scientific and Technological Program	62	
	<hr/>	
Subtotal, obligations		<u>\$6,818</u>
Unobligated balance available, end of year		<u>\$2,791</u>
Total, fiscal year 1984 availability for Trust Funds/Donations		<u>\$9,609</u>

SOURCES: Fiscal Year 1986 Supplementary Budget Schedules, Fiscal Year 1986 Budget to Congress and NSF accounting records

Appendix C

Patents and Inventions Resulting from Activities Supported by the National Science Foundation

During fiscal year 1984, the Foundation received 129 invention disclosures. Allocations of rights to 87 of those inventions were made by September 30, 1984. These resulted in dedication to the public through publication in 20 cases, retention of principal patent rights by the grantee or inventor in 62 instances, and transfer to other government agencies in 5 cases. Licenses were received by the Foundation under 17 patent applications filed by grantees and contractors who retained principal rights in their inventions.

Patents issued for FY 1984 were as follows:

Number	Title	Institution
4,271,033	Transition Metal Complex Catalysts	California Institute of Technology
4,310,505	Lipid Vesicles Bearing Carbohydrate Surfaces as Lymphatic Directed Vehicles for Therapeutic and Diagnostic Substances	California Institute of Technology
4,310,506	Means of Preparation and Applications of Liposomes Containing High Concentrations of Entrapped Ionic Species	California Institute of Technology
4,318,581	Optical Holographic Content-Addressable Memory System for Truth Table Look-Up Processing	Georgia Tech
4,349,521	Ruthenium Carbonylates, Ruthenium Carbonyl Hydrides, Osmium Carbonylates and Their Preparation	Ohio State Univ. Research Foundation
4,376,647	Process for Treating Sulfide-Bearing Ores	University of Utah
4,389,347	Synthesis of Heteronuclear Tri-Osmium Carbonyl Hydrides under Gaseous Hydrogen	Ohio State Univ. Research Foundation
4,396,713	Restriction Endonuclease Fingerprinting of Kinetoplast DNA Minicircles	Regents of University of California
4,400,470	Use of Co-Cultures in the Production of Ethanol by the Fermentation of Biomass	Wisconsin Alumni Research Foundation
4,400,532	Cryogenically Controlled Direct Fluorination Process, Apparatus and Products Resulting Therefrom	Massachusetts Institute of Technology
4,404,256	Surface Fluorinated Polymers	Massachusetts Institute of Technology
4,417,327	Dynamically Operated Structured Logic Array	University of Utah
4,379,931	Metal Extraction from Solution and Novel Compounds Used Therefor	Dow Corning Corp.
4,389,347	Synthesis of Heteronuclear Tri-Osmium Carbonyl Hydrides under Gaseous Hydrogen	Ohio State Univ. Research Foundation
4,399,360	Transmission Electron Microscope Employing Sequential Pixel Acquisition for Display	University Patents, Inc.
4,407,956	Cloned Cauliflower Mosaic Virus DNA as a Plant Vehicle	Regents of the University of California
4,410,402	Degradation of Halogenated Carbon Compounds	Regents of the University of California
4,421,654	Metal Extraction from Solution and Novel Compounds Used Therefor	Dow Corning Corp.
4,425,432	Propagation of Microbial Cells on Single Carbon Products	Wisconsin Alumni Research Foundation
4,427,580	Method for Separation and Recovery of Proteins and Nucleic Acids from Nucleoproteins, Using Water Destructuring Salts	Cornell Research Foundation
4,427,595	Catalyst Composition to Effect Metathesis of Acetylenes	Massachusetts Institute of Technology
4,427,886	Low-Voltage Field Emission Electron Gun	Wisconsin Alumni Research Foundation
4,428,770	Methods of Manufacturing Metal from a Melt, Determination of Sulfur and Carbon Therein, Sensors Therefor, and Solid Electrolyte Compositions for Said Sensors	University Patents, Inc.
4,468,694	Metal Extraction from Solution and Immobilized Chelating Agents Used Therefor	Dow Corning Corp.
4,466,362	Method of Removing Sulfur and Other Contaminants from the Coal in Coal-Oil Slurries	Massachusetts Institute of Technology

Appendix D

Advisory Committees for Fiscal Year 1984

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Laboratory and Vice President,
California Institute of Technology

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Associate Commissioner for Education for the
State of Texas

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Chairman, Nuclear Engineering Department
Iowa State University

William T. Coleman, Jr.
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Washington, DC

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Entertainer/Educator
Greenfield, MA

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President
The Evergreen State College
Olympia, WA

Patricia Albjerg Graham
Dean, Graduate School of Education
Harvard University

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Optimization Technology, Inc.
Los Altos, CA

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Pfizer, Inc.
New York, NY

Katherine P. Layton
Teacher
Mathematics Department
Beverly Hills High School

Ruth B. Love
General Superintendent
The Chicago Board of Education

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University of Minnesota

Frederick Mosteller
Chairman, Department of Health Policy and
Management
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M. Joan Parent
President, National School Boards Association
Foly, MN

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Professor of Chemistry
University of Utah

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Research and Defense Systems
Gould, Inc.
Rolling Meadows, IL

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Carnegie-Mellon University

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University of Texas, Austin

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National Center for Atmospheric Research
Boulder, CO

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Chairman, Computer Science and Engineering
Department
University of South Florida, Tampa

James F. Gilbert
University of California at San Diego
La Jolla, CA

Anthony C. Hearn
Information Sciences Department
Rand Corporation
Santa Monica, CA

Neal Lane
Chancellor
University of Colorado
at Colorado Springs

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Lawrence Livermore Laboratory
Livermore, CA

Cyrus Levinthal
Department of Biological Sciences
Columbia University

David C. Nagel
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Moffett Field, CA

Steven A. Orszag
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Department of Economics
University of Minnesota
Minneapolis, MN

Mark A. Stadtherr
Chemical Engineering Department
University of Illinois, Urbana

Frank H. Stillinger
AT&T Bell Laboratories
Murray Hill, NJ

Kenneth G. Wilson
Newman Laboratory of Nuclear Studies
Cornell University

Technical Review Committee for Advanced Scientific Computing

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Department of Commerce
Washington, DC

Robert R. Borchers
Associate Director, Computations
Lawrence Livermore Laboratory

Roger Buck
NSA
Columbia, MD

Sidney Karin
GA Technologies, Inc.
San Diego, CA

James R. Kasdorf
Westinghouse Electric Corporation
Pittsburgh, PA

Victor Peterson
Director of Astronautics
NASA/AMES Research Center
Moffett Field, CA

Paul A. Rotar
NCAR
Scientific Computing Division
Boulder, CO

Larry Travis
Director of Academic Computing
University of Wisconsin, Madison

Leland H. Williams
President
Triangle University Computation Center
Research Triangle Park, NC

Conrad Wogrin
University of Massachusetts
Computing Center
Amherst, MA

Jack Worlton
Los Alamos National Laboratory
Los Alamos, NM

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in Science and Technology**

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Mills College
Oakland, CA

Kimiko O. Bowman
Oak Ridge National Laboratory
Oak Ridge, TN

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Polytechnic Institute of New York

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Alexander Cruz
Department of Environmental Population and
Organismic Biology
University of Colorado, Boulder

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University of Texas, San Antonio

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Administration
Seattle, WA

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Native American Studies Program
University of California, Berkeley

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National Technical Institute for the Deaf
Rochester, NY

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Systems
Purdue University

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Program Head AAAS
Office of Opportunities in Science
Washington, DC

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Associate Professor
Department of Natural Science
Michigan State University

Shirley M. McBay
Dean for Student Affairs
Massachusetts Institute of Technology
Cambridge, MA

Sheila Pfafflin
American Telephone & Telegraph Co.
New York, NY

Anne B. Swanson
Associate Professor of Chemistry
Edgewood College
Madison, WI

Sally Wood
Department of Electrical Engineering
Cornell University

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Mary Jane Osborn
Professor and Head,
Department of Microbiology
University of Connecticut

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Washington State University, Pullman

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Rockefeller University
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National Academy of Sciences

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