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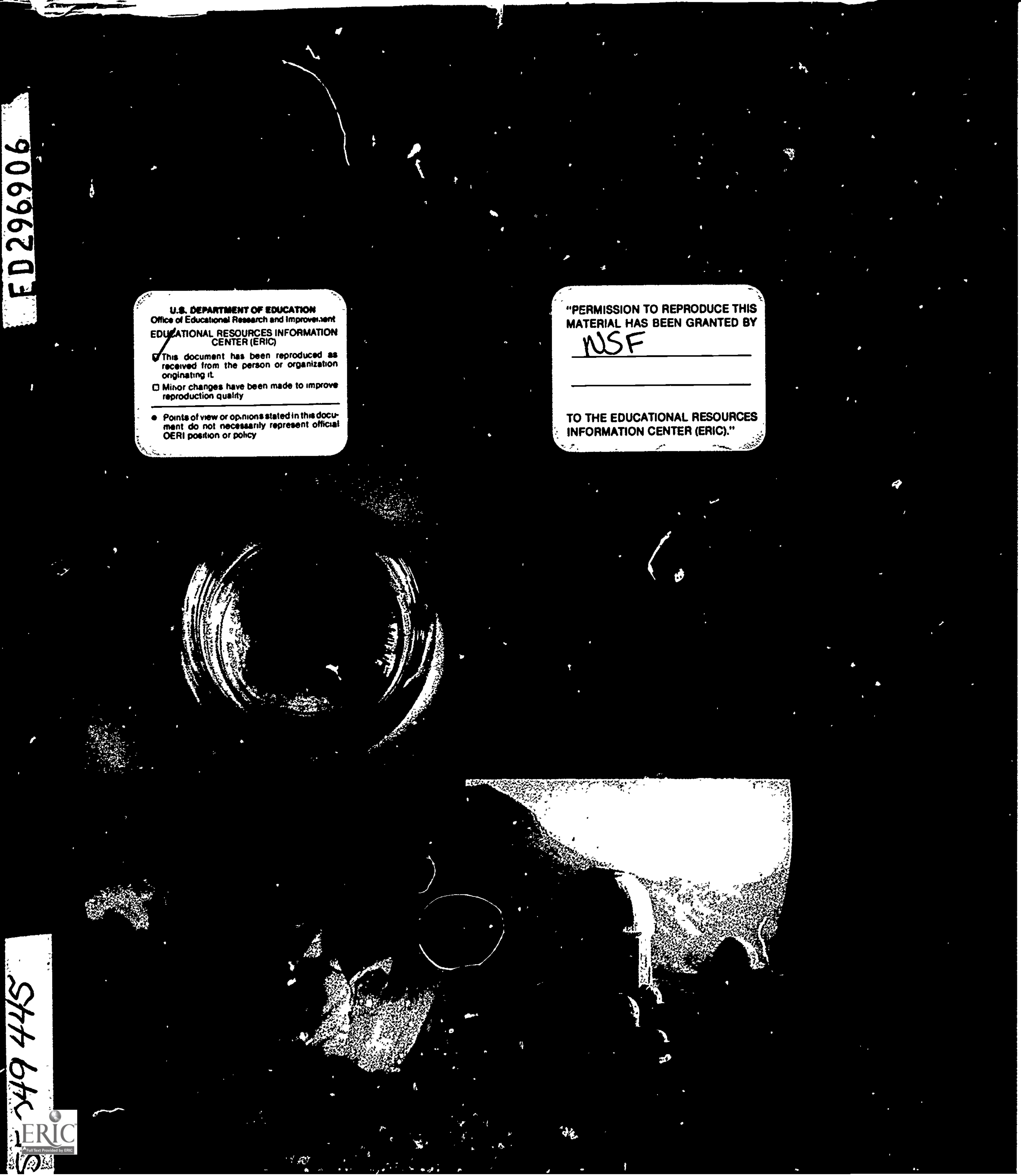
ABSTRACT

The imbalance between the supply and demand for new knowledge is a very important feature with regard to science and engineering. Whereas the supply of new knowledge appears unlimited, the demand for new knowledge is much greater. In the years to come, more knowledge will be needed to cope with world problems. Knowledge is a most important resource along with the scientists and engineers who produce it. Many believe that increasing the supply of knowledge requires solving the problems of education and devoting the necessary resources to basic research. This publication contains seven chapters, a director's statement, highlights, awards, operational and organizational news, and a conclusion. The first chapter gives perspectives for the 1990s. Chapter 2, on human resources and education, outlines precollege education, undergraduate and graduate education, other activities, and public outreach. Chapter 3 explains disciplinary research in fields including the sciences, mathematics, and small businesses. Chapter 4 deals with basic research of centers and groups, and instrumentation. Included are three appendices including: (1) a list of National Science Foundation and National Science Board Members; (2) the patents and financial report; and (3) a list of advisory committees and chairpersons. (RT)



# 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 and engineering across all disciplines. In contrast, other federal agencies support research focused on specific missions, such as health or defense. The Foundation is also committed to expanding the nation's supply of scientists, engineers, and science educators.

NSF funds research in all fields of science and engineering. It does this through grants and contracts to more than 2000 colleges, universities, and other research institutions in all parts of the United States. The Foundation accounts for about 25 percent of federal support to academic institutions for basic research.

NSF receives more than 32,000 proposals each year for research, graduate fellowships, and math/science/engineering education; it makes more than 15,000 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.

The Foundation is run by a presidentially appointed Director and Board of 24 scientists and engineers, as well as top university and industry officials.

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 advisers, primarily from the scientific community, who serve on formal committees or as ad hoc reviewers of proposals. This advisory system, which focuses on both program direction and specific proposals, involves more than 59,000 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 responsiblity for such findings or their interpretation.

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

In accordance with federal statutes and regulations and NSF policies, no person on grounds of race, color, age, sex, national origin, or disability shall be excluded from participation in, denied the benefits of, or be subject to discrimination under any program or activity receiving financial assistance from the National Science Foundation.

*Facilitation Awards for Handicapped Scientists and Engineers* (FAH) provides funding for special assistance or equipment to enable persons with disabilities (investigators and other staff, including student research assistants) to work on an NSF project. See the FAH announcement or contact the FAH Coordinator at (202) 357-7456.

The National Science Foundation has TDD (Telephonic Device for the Deaf) capability, which enables individuals with hearing impairment to communicate with the Division of Personnel and Management about NSF programs, employment, or general information. This number is (202) 357-7492.

# National Science Foundation
## Annual Report 1987

Annual Report for Fiscal Year 1987

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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 1987 of the National Science Foundation, for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,

Erich Bloch
*Director, National Science Foundation*

*The Honorable*
*The President of the United States*

# CONTENTS

# DIRECTOR'S STATEMENT

As we look back on 1987 and ahead to the last years of the twentieth century, the most striking feature on the landscape of science and engineering is imbalance between the supply and demand for new knowledge.

On the one hand, the supply of new knowledge seems unlimited. Superconductivity has captured our imagination with the possibility of much more efficient transportation and electrical power systems. Supercomputers and "chaos theory" in mathematics promise to help us understand such complex phenomena as weather patterns, turbulence in fluid systems, and the distribution of biological resources.

Biotechnology is already a growing industry, driven by basic research in biology and especially in genetics. It is already clear that these sciences will create continuing revolutions in agriculture and health care.

American manufacturing, which is essential to our economic well-being, is beginning to make a comeback as new materials, robotics, computer-aided engineering design, and other technologies emerge from basic research and find application.

Is this "supply" of new knowledge enough? Is it even too much? Some critics argue that knowledge is developing too rapidly, that we should slow down and give our social systems time to adapt. Yet the demand for new knowledge is much greater than the supply.

Our rapidly developing knowledge of the effect of chlorofluorocarbons on the ozone layer is a good example-only intensive use of the most advanced

science can help us understand this problem in time to solve it before permanent damage is done to the environment.

***"Increasing the supply of knowledge requires solving two serious problems. First among them is education . . . The second problem is to devote the necessary resources to basic research."***

Economic competitiveness is another example. New knowledge created through basic research is the source of new products and manufacturing processes for the international marketplace—and thus the key to maintaining American prosperity and our standard of living.

Ozone and economic competitiveness are only two current examples of the problems our civilization will face in coming decades. We have no way of knowing what new problems will appear tomorrow, or next year. But we can be certain that we will need still more knowledge to cope with these problems. In an uncertain world, knowledge—along with the scientists and engineers who produce it—is our most important resource.

Increasing the supply of knowledge requires solving two serious problems. First among them is education: we must find the ways and the means for our schools to teach all our young people basic concepts in science and mathematics. And many more students—especially women and minorities—must be encouraged to go beyond the basics into preparation for careers in science or engineering. In an increasingly technological world, many more of our leaders in industry, in government, and in academia must have technical training if we are to control events.

The second problem is to devote the necessary resources to basic research. We spend about two-tenths of one percent of our GNP on such research—not much, when we consider its importance. And the fraction has not changed significantly in 20 years, although science and engineering have become vastly more important.

There are no easy solutions to these problems. But the search for solutions deserves our best efforts, and it defines the mission of the National Science Foundation as we move toward the 21st century.

*Erich Bloch*
*NSF Director*

8

**Then ye who now on heavenly nectar fare,**
**Come celebrate with me in song the name**
**Of Newton, to the Muses dear; for he**
**Unlocked the hidden treasures of Truth:**
**So richly through his mind had Phoebus cast**
**The radiance of his divinity,**
**Nearer the god no mortal may approach**

—Edmund Halley in his preface to Isaac Newton's *Principia*

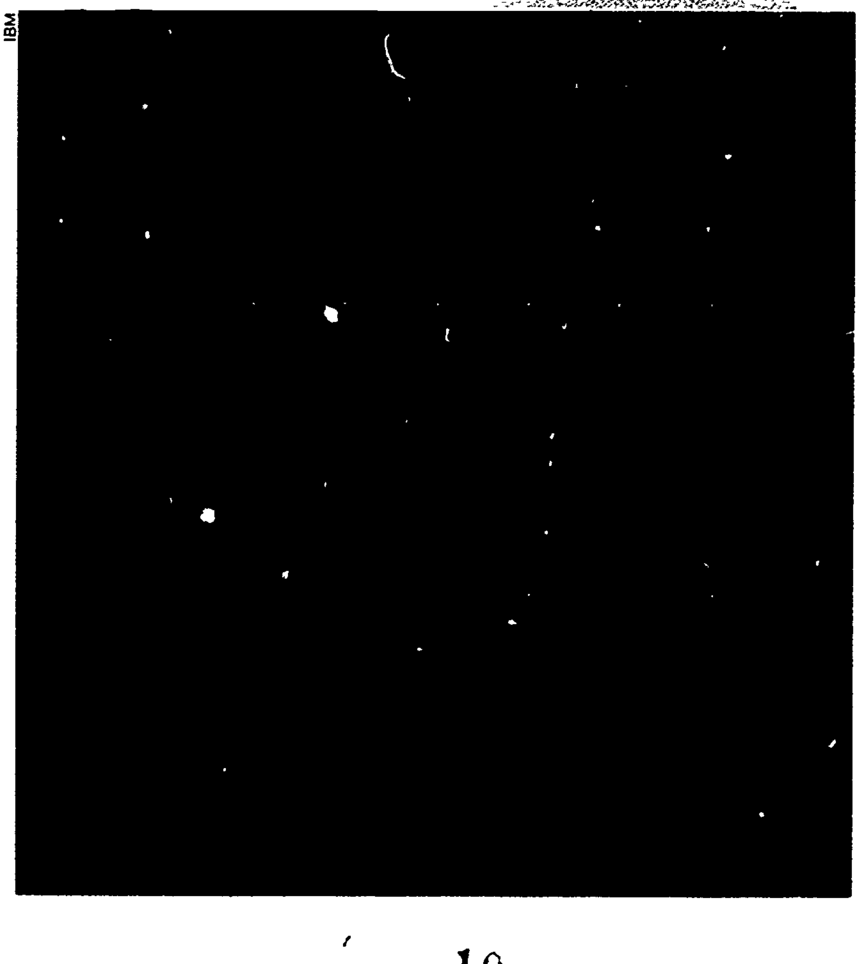
In 1687, Isaac Newton revolutionized the natural sciences with the publication of his landmark book, *Philosophiae Naturalis Principia Mathematica*, more commonly known as the *Principia*. Among Newton's achievements in his *Principia*, written in only 18 months, were mathematical expressions for the laws of motion and gravitational attraction. A new universe of information opened up to scientists: Newton explained the orbits of the planets around the sun, irregularities in the moon's orbit, and the cause of ocean tides.

In 1987, the 300th anniversary of Newton's *Principia*, new discoveries once again made news in the natural sciences, especially in astronomy and materials science. Astronomers detected supernova 1987A, the brightest exploding star visible from earth since 1604. And the discovery of materials that conduct electricity without resistance or energy loss at higher temperatures than few dreamed possible has been called the most important scientific finding of the latter half of the twentieth century.

The year 1987 could be dubbed "the year of the supers" — a time of supercomputer applications, supernova sightings, superconducting materials discovered. But among all the scientific stories of the year, the discovery of new types of superconductors led the way. Ever since a Dutch scientist in 1911 found that a pure crystal of mercury lost all resistance to electric current when cooled to ultracold temperatures — 4 degrees above absolute zero or -460 Fahrenheit — scientists have searched for materials that are superconducting at higher temperatures. For 75 years that search turned up materials that required only slightly less cooling to become superconducting. A steady and costly supply of liquid helium was needed for superconducting magnets and circuits to operate.

IBM

High-Temperature Superconductor. This solid model of a crystal structure was produced using software developed by IBM. As modeled here, the ingredients of this compound are barium (green), yttrium (silver), copper atoms (blue), and oxygen atoms (red). The compound generated great interest because of the observation of superconductivity with a critical temperature above the boiling point of liquid nitrogen.



IBM

Magnetic levitation. A modern permanent magnet floats above a yttrium-barium-copper oxide superconductor at liquid nitrogen temperature (−321F). In order to expel the permanent magnetic field from the superconductor, a current flows near the surface of the superconductor to produce the opposing field.

Then, in 1986, IBM researchers in Zurich reported the onset of superconductivity in a ceramic compound at a temperature a few degrees higher than previously observed.* The report sparked the interest of a number of research teams, including one headed by solid-state physicists *Paul Chu* at the University of Houston and *M.K. Wu* at the University of Alabama at Huntsville. The team reproduced the Zurich results and in early 1987 took a giant leap forward: using a new ceramic compound of their own concoction, Chu and Wu achieved the superconducting state at temperatures more than a hundred degrees higher (in Fahrenheit) than ever before.

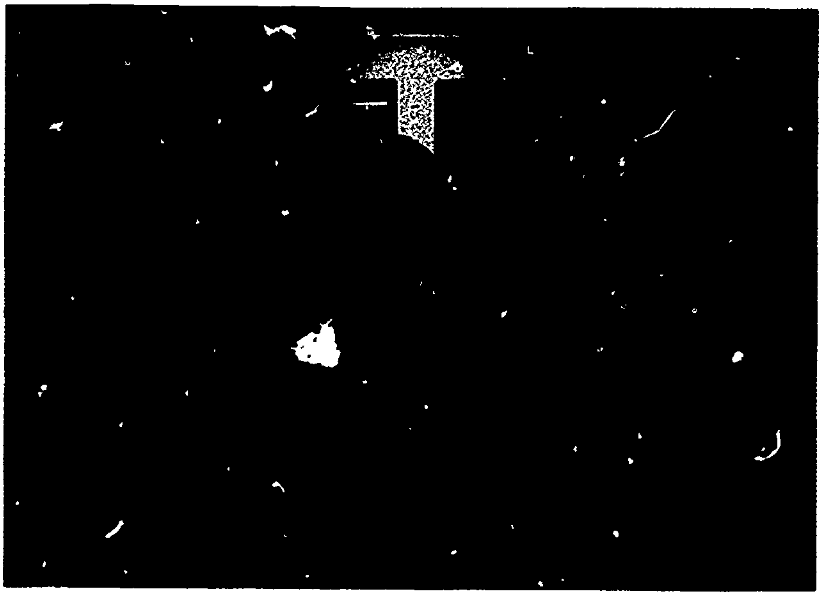
The finding sent puzzled theorists back to the blackboard and experimentalists rushing to their laboratories. The discovery also meant that an important economic barrier had been crossed. Since ceramic superconductors become superconducting using only liquid nitrogen (at about 40 cents a gallon a cheap and plentiful coolant), potential applications to daily life may be enormous. For example, if the new materials can be fashioned into circuits or wires that can carry large currents without losing their superconducting properties, they may result in such applications as power generators and transmission lines that do not experience power loss, or large magnets that could be used for more precise medical imaging.

Creating powerful magnetic fields and electric currents, high-temperature superconductors would provide energy at a fraction of the cost needed to operate older superconducting circuits. Levitating trains, floating in a superconducting magnetic field above the tracks, could glide effortlessly at hundreds of miles per hour without encountering friction from the metal rails. Brookhaven National Laboratory on Long Island, NY, has demonstrated that a cable made of one of the older, low-temperature superconductors, although only 16 inches thick, could carry one-eighth of the electricity needed by New York City on the hottest day of the year.

Paul Chu was serving as a year-long director in the NSF solid-state physics program when his discovery was announced, and he is a long-time recipient of NSF research funds. M.K. Wu's laboratory in Huntsville is supported by an NSF activity called Experimental Program to Stimulate Competitive Research (EPSCoR).

*The Zurich team was among the 1987 Nobel Prize winners, based on this superconductivity work.

**Research on superconductivity. M.K. Wu (University of Alabama at Huntsville) studied superconductivity through an NSF grant designed to stimulate competitive research in certain states.**



Super researchers. Paul Chu (center) and his research team at the University of Houston have made important breakthroughs in discovering new high-temperature superconductors.

Other research teams, including those at AT&T Bell Labs, IBM, and in Japan, Switzerland, and China have also reported superconductivity at record high temperatures.

The almost weekly announcements on superconducting materials created a flurry of new activity in the scientific community worldwide. An evening session devoted to superconductivity at the March 1987 meeting of the American Physical Society turned into an all-nighter with standing room only; scientists still talk about the session as "the Woodstock of Physics." And at a Spring 1987 meeting of the National Science Board, 15-year-old Heidi Grant, the daughter of IBM superconductor researcher Paul Grant, demonstrated one of the ceramic materials she had made for just a few dollars in her father's laboratory.

For all the excitement, the reasons why materials become superconducting at high temperatures are not well understood. That certain materials lose all resistance to electric current at any temperature is a startling concept: even good "normal" conductors, such as copper wire, usually require a battery or other source of energy to keep current moving.

At the submicroscopic level, the electrons that make up current normally collide with atoms and impurities in the conducting material. These collisions waste energy and the electric current is slowed. But in the old, low-temperature superconductors, according to an accepted theory, electrons pair off at lower temperatures and shield one another from these energy-depleting collisions. At higher temperatures, however, the electron pairs break and superconductivity is lost. Theoreticians, aware of the existence of high-temperature superconductors, are now puzzling over the physical mechanism that makes superconductivity possible at those temperatures.*

At a government-sponsored conference on superconductivity held during the summer of 1987, President Reagan announced an 11-point plan to promote further work in superconductivity and ensure U.S. readiness to take the lead in commercial applications of the new research. NSF support in this area has approximately doubled, to about $10 million. Included in this amount is $1 million that NSF added to its support of materials research at three of the Materials Research Laboratories it funds. NSF also set aside $600,000 for rapid start-up grants for engineers working on processing the new superconducting materials.

*In January 1988, Paul Chu announced the discovery of yet another compound that became superconducting at about 254 degrees below zero Fahrenheit. This compound is made of bismuth, aluminum, strontium, calcium, and copper oxide.

Astronomy also had a remarkable year in 1987—a year of both illuminating discoveries and puzzling results. From the sighting of the brilliant supernova explosion known as 1987A to surprising evidence for the existence of seven new galaxies in a region thought to be empty space, astronomers were deluged with new information about the universe.

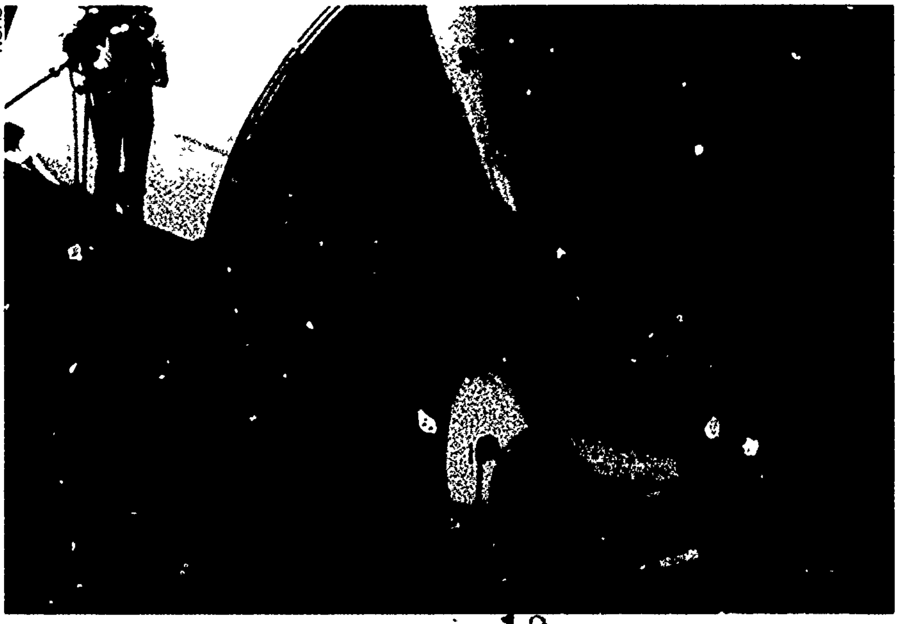
### "Super" Star Draws Worldwide Research Effort

Astronomers will long remember the night of February 23, 1987. On a desolate mountaintop in northern Chile, a Canadian astronomer glimpsed an unfamiliar bright spot on a freshly exposed photographic plate of the Magellanic Cloud, a galaxy a billion billion miles from earth. The spot was no chemical aberration: an object so brilliant it could be seen with the naked eye had suddenly appeared in the galaxy. Scientists glimpsed nature at its most explosive: supernova 1987A, the first of its kind sighted in 1987 and the brightest visible from earth since 1604, had been born.

Supernovas are the glowing clouds of gas and dust particles hurled into space when stars several times as massive as the sun collapse under their own gravitational pull. Such explosions are not rare, but because most are too far and too faint to be observed in detail, the quest to understand how they happen has largely been limited to theoretical analysis and computer modeling. But supernova 1987A, a living model burning with the light of 100 million suns in a neighboring galaxy, put many existing theories to the test. And since the explosion was visible only from the Southern Hemisphere, observatories in the clear mountain air of Chile, including the NSF-funded Cerro Tololo Inter-American Observatory, became the focus of worldwide research efforts.

Only hours after announcement of the discovery, Cerro Tololo telescopes captured some of the first detailed images of the new supernova. Analysis of these images and the light produced by the February explosion revealed that the supernova was caused by the collapse of a star known as a supergiant. Further studies found that the supergiant was of a type commonly believed to be too hot to give rise to a supernova, forcing scientists to revise their theories somewhat.

NOAO



**Observing the supernova. Astronomers used the Curtis-Schmidt telescope at Cerro Tololo to photograph and observe supernova 1987A.**

Supernova 1987A. Located in the Large Magellanic Cloud near the Tarantula nebula, the brilliant supernova 1987A burns with the light of 100 million suns and is the closest supernova seen since the invention of the telescope. This wide-field photograph was taken by the Curtis-Schmidt telescope at the Cerro Tololo Inter-American Observatory in Chile.

National Optical Astronomy Observatories (NOAO)

Supporting evidence that a supergiant had given rise to the supernova came from photographic plates of the Large Magellanic Cloud taken two decades ago at Cerro Tololo. *Nicholas Sanduleak*, then a staff astronomer, had analyzed the light and catalogued the position of a number of stars from the galaxy, including a supergiant now known as Sanduleak -69 degrees/202. Twenty years later, the location of the supernova closely matched the position of the Sanduleak star. And ultraviolet studies revealed that the star had disappeared after the supernova explosion. The close connection between the two was unmistakable.

Other unusual features of supernova 1987A were also uncovered at Cerro Tololo. Using a special rapid exposure photographic technique, astronomers discovered an unexpected, glowing companion near the supernova. And while light from most supernovas reaches a peak intensity quickly, supernova 1987A increased its brilliancy for three months, equalling the brightness of a star in the Big Dipper before slowly fading from view.

Scientists have since turned their attention to exploring the dense, collapsed star that is the burned out remnant of the explosion, along with the gases still racing outward into space — there to mingle with gases left over from the time when the star was formed. In fact, NASA's Solar Maximum Satellite and two Australian balloon experiments have already provided additional evidence that exploding stars such as the supernova create key heavy elements, including metals, from lighter elements.

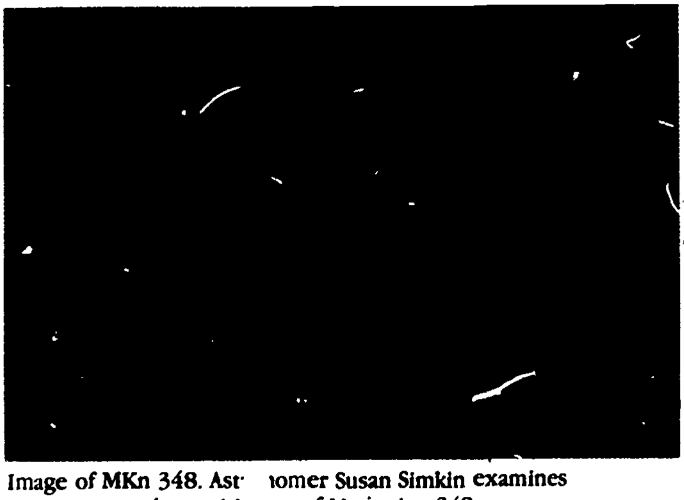
The balloon-lofted instruments involved were highly sensitive detectors of gamma radiation; they made the first clear detection of gamma-ray emissions from a stellar explosion and helped scientists deduce the elements that produced the radiation.

The supernova attracted both astronomers who study the large scale and scientists who search for subatomic relics of the stellar explosion. In a salt mine far below ground in Lake Erie, in the Kamioka lead and zinc mine in Japan, in the Mont Blanc Tunnel linking France and Italy, and in another tunnel under Mount Elbrus in the Soviet Union, physicists monitored detectors for the elusive subatomic particles called neutrinos They are predicted to be produced during a supernova, preceding the emission of visible light. Neutrinos were detected, affirming our understanding of how supernovas occur.

## Largest Galaxy Discovered

Astronomers discovered in 1987 the largest galaxy yet known in the universe, a giant spiral 13 times as big as our own Milky Way galaxy.

Known as Markarian 348, the galaxy had first been observed by optical telescope more than 20 years ago, but was thought to be the size of the Milky Way More recently, Markarian 348 drew the attention of *Susan Simkin*, an astronomer at Michigan State University. Simkin was making a study of very bright galaxies, including Markarian 348.



National Radio Astronomy Observatory

**Image of MKn 348. Astronomer Susan Simkin examines a computer-enhanced image of Markarian 348.**

Simkin and her collaborators studied the radiation from the galaxy using both the optical telescope at Mount Palomar Observatory in California and the Very Large Array (VLA) radio telescope, an NSF-supported facility in New Mexico. The data from the radio telescope surprised the research team Markarian 348 had a diameter of 1.3 million light years, the largest single galaxy yet observed. A light year is the distance light travels in a year, about six trillion miles

According to Simkin, the high resolution of the VLA telescope — actually an assemblage of 27 radio antennas that move on railroad tracks — was crucial to accurate measurement of the distant galaxy's size

Simkin's collaborators were *Jacqueline van Gorkom*, a staff astronomer at the National Radio Astronomy Observatory; *John Hibbard*, a former summer student at the VLA, and *Su Hong-jun* from the Purple Mountain Observatory in the People's Republic of China.

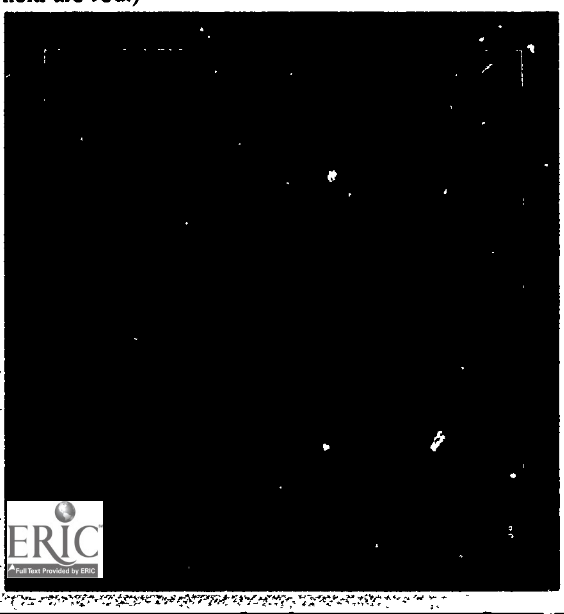
## Other Astronomy Findings

Astronomers from several institutions — using a variety of optical telescopes — have discovered seven rare galaxies in a portion of the universe that was presumed to be empty space. Their work was done at Kitt Peak National Observatory, an NSF-supported facility in Arizona. The galaxies, unusual because they include energetic gases that indicate they may be giving birth to new stars, are located in the direction of the constellation Bootes. The "empty" region where the galaxies were found is so vast that 2,000 galaxies the size of the Milky Way would be expected in that space.

Discovery of the galaxies has important repercussions for theories on the formation and clustering of galaxies and on the way matter is distributed in the universe.

In a separate research effort, a team of British and American astronomers has found that our own galaxy, the Milky Way, and thousands of its neighbors are speeding across space at the rate of 400 miles per second. The finding intrigued and baffled the scientific community, since none of the theories that explain the formation and structure of the universe can account for the observed motion One of many conjectures about the unexplained motion, known as large-scale streaming, is that the galaxies are being pulled by the gravitational force of some huge, as yet undiscovered object. Research that led to the discovery was conducted at observatories worldwide, including the Kitt Peak National Observatory.

**Largest galaxy.** Astronomers in 1987 found that Markarian 348, a giant spiral galaxy first sighted more than 20 years ago, is the largest galaxy yet known in the universe. It is 13 times as large as the Milky Way. (In this composite optical image, cold, neutral hydrogen is shown in blue; stars in the galaxy and surrounding field are red.)



**Collaborative effort.** Su Hong-jun, at the Purple Mountain Observatory in the People's Republic of China, was a collaborator in Markarian 348 research.

Researchers at the Francis Bitter National Magnet Laboratory at MIT have built a magnet that produces pulses of magnetic field twice as strong as the largest steady-state device. Previous research at the laboratory led to creation of the world's largest steady-state magnetic field (described in NSF's FY 1986 annual report).

This new tool, which generates a magnetic field that peaks in strength every few minutes, gives scientists a highly accurate and inexpensive probe for studying the magnetic and electronic properties of metals, semiconductors, and superconductors — including the new superconducting materials only recently discovered.

Working in collaboration with Supercon, Inc., a small company in Massachusetts, *Simon Foner* of the MIT laboratory developed a copper-niobium wire whose mechanical strength and high electric and thermal conductivity were used to create a magnetic field of 68.4 tesla, more than a million times as large as the earth's field. The high intensity and relatively long duration of the magnetic pulse — about five-thousandths of a second — allow researchers to extend the measurements with a weaker steady-state magnet. One important application is in measuring the "critical field" of a superconductor, the magnetic field beyond which the material no longer allows no-resistance flow of electric current. Measuring the critical field of each of the new superconductors aids scientists in understanding these exciting and sometimes puzzling materials.

Bitter National Magnet Laboratory, MIT

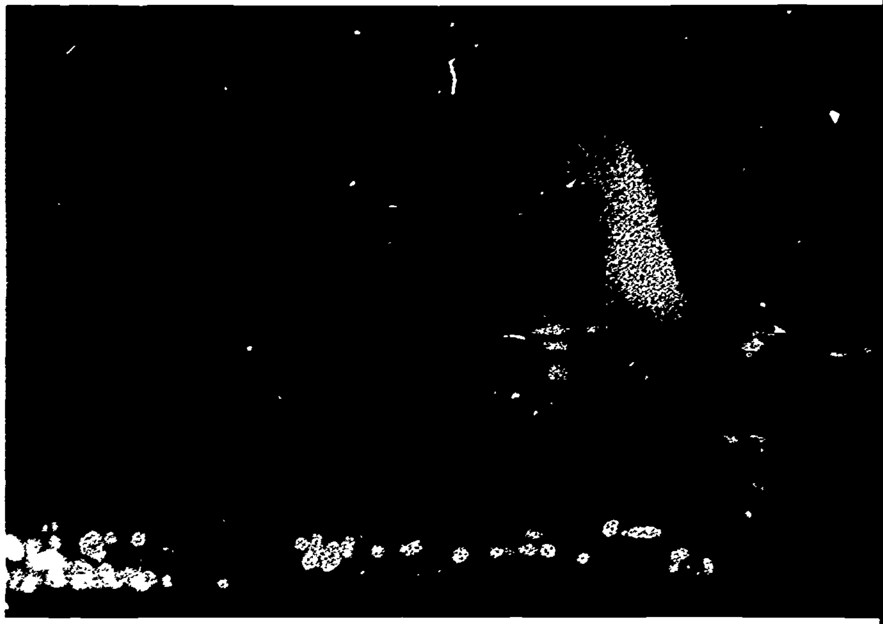
**Pulsed magnetic field. This MIT magnet produces a pulsed magnetic field twice as strong as the largest steady-state device. It gives scientists a highly accurate and inexpensive tool for probing the properties of many materials, including the new superconductors. Hardened steel shell contains the highly stressed magnet.**

Antiparticles are the mirror images of subatomic particles such as the proton or electron, possessing nearly identical properties, but with the opposite electric charge. An antiproton, for example, is the equivalent of a proton with a negative charge. Although the study of antiparticles is crucial for testing fundamental theories about how the universe was formed, antiparticles can be created in large quantities only at high energies and high velocities. Scientists have been unable to slow down these particles long enough to analyze them precisely.

The antiproton has proved particularly elusive. But a collaboration of U.S. and West German researchers led by experimental physicist *Gerald Gabrielse* at Harvard University found a method for trapping these particles for periods up to 10 minutes in a container the size of a matchbox. The researchers began with a beam of energetic antiprotons produced by the large accelerator at the European Center for Nuclear Research (CERN) in Switzerland. A CERN apparatus called the Low Energy Electron Ring removed large amounts of energy from the beam, but the researchers were still faced with capturing antiprotons possessing millions of electron-volts of energy. And due to tight scheduling, they had only 24 hours to perform the experiment.

First the scientists passed the antiproton beam through a thick metal disc, causing the beam to lose energy by collision with electrons inside the metal. Next, the researchers used powerful electric and magnetic fields to confine the energetic antiparticles inside a vacuum chamber only a few inches long. A large negative voltage applied alternately to electrodes placed at the front and back of the chamber kept the antiparticles bouncing back and forth, while a strategically placed magnetic field prevented the antiparticles from slipping out from the chamber sides.

Succeeding in only a day, the investigators for the first time confined thousands of antiprotons in the chamber for tenths of seconds. Five antiprotons were trapped for as long as 10 minutes. As of this writing, the scientists expect to trap antiprotons for more than a day, enabling them to measure the mass of the antiparticles at least 100 times as precisely as ever before. Physical theories about elementary particles — the basis of our understanding about how matter is put together — predict that the mass of the antiproton must be exactly the same as its mirror twin, the proton. But experiments have not ruled out a tiny deviation. If the mass of an antiproton is found to be more or less than that of a proton, it could be one of the most significant discoveries in physics in quite a few years.



**Antiparticle research. Shown here are electrodes for the ion trap used by U.S. and West German researchers to capture and hold antiprotons.**

# Antarctic Ozone Layer: Research Continues

Jack Renine

**Balloon Launch. Scientists launch an instrumented balloon at Amundsen-Scott South Pole Station in November 1987. Measurements showed ozone to be returning to the stratosphere above the South Pole after a depletion over Antarctica of several months during the springtime "ozone hole." The ozone dramatically increased by 25 percent in 24 hours and returned to normal over a period of several days. Scientists relate the hole to chlorofluorocarbons (CFCs) used throughout the world in industrial applications and to atmospheric conditions unique to Antarctica.**

Scientists investigating the ozone "hole" that occurs over Antarctica between September and November (see NSF Annual Report for FY 1986) found in 1987 that the depletion of the ozone layer there was more pronounced than in previous years. Preliminary results suggest that both chemical and meteorological factors may produce the phenomenon. Moreover, the ozone hole was evident over the tip of South America as well.

The chemical products suspected of depleting ozone, known as chlorofluorocarbons, are widely used in refrigeration, foam insulation, and some aerosol sprays.

Researchers at McMurdo Station, the U.S. Antarctic Program's station about 840 miles from the South Pole, found in 1987 that the ozone hole contained well over 100 times the usual concentration of the compound chlorine monoxide, which is produced by chlorofluorocarbons and depletes ozone through a complex chain of chemical reactions. Preliminary data analysis also suggests that Antarctica's extremely cold stratosphere and circulation patterns may contribute significantly to the ozone problem.

During the annual depletion or hole, about 35 to 50 percent of the ozone disappears. Recovery usually occurs around late November or early December. The hole, first reported by British scientists in 1985, is about five miles thick and covers an area more than twice the size of the United States. Understanding the depletion process is important, because atmospheric ozone shields the earth from most of the sun's harmful ultraviolet rays, which can cause skin cancer in human beings and can harm both animals and plants.

In August 1987 seven teams of U.S. scientists participated in the second National Ozone Expedition (NOZE). NOZE is a cooperative effort sponsored by NSF (the lead U.S. agency on the continent), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Chemical Manufacturers' Association. The scientific leader of the expedition, atmospheric chemist *Susan Solomon* of NOAA, and her colleagues used molecular properties of light absorption to measure concentrations of ozone and chemicals suspected of playing a role in ozone depletion.

Other scientists included the father-son team of *David* and *Frank Murcray* from the University of Denver. The Murcrays analyzed the absorption of the sun's infrared radiation by a number of gases in the antarctic atmosphere. *Bruce Morley* and *Edward Uthe* of SRI International used an instrument (called a lidar) specially designed for the expedition to shoot a fine beam of light at the antarctic stratosphere. Information on the time it took for the beam to return to earth helped the researchers determine the location of polar clouds and layers of aerosols.

In September 1987 two NASA airplanes fitted with special instruments to collect atmospheric data flew into and around the ozone hole. The data they collected complemented results from ground-based investigations at McMurdo Station. Then at the end of 1987 scientists reported that the winter mass of extremely cold air over the White Continent had stayed about three weeks longer than it did the year before — an event that may be directly related to the ozone hole. (The antarctic air may have warmed more slowly because there was less ozone to absorb the sun's heat.)

At this writing, the 1987 data are still being analyzed, and planning for a third NOZE expedition is under way.

# New Technique Finds Earth's Core Hotter than Expected

Using a powerful gun that accelerates projectiles to enormous speeds, researchers have determined that the earth's center is thousands of degrees hotter than previously thought.

Geophysicists have long known that the earth's outer core is made of molten iron under high pressure. Since the core must be at least as hot as the temperature to melt iron, discovering iron's melting point at high pressure gives the minimum possible temperature of the core. But previous efforts to determine the melting point relied on extrapolations from measurements of iron melted at much lower pressures. Scientists had estimated that the earth's core was about 7100 degrees Fahrenheit.

Core of the matter. Thomas J. Ahrens checks procedures for firing Caltech's light gas gun, which simulates the high pressures at the earth's core.

But using specially designed guns, the largest 106 feet long and weighing 35 tons, California Institute of Technology researchers, collaborating with the University of California at Berkeley, found a better way to simulate conditions at the earth's center. The guns enabled geophysicist *Thomas J. Ahrens* and his collaborators to fire plastic and tantalum bullets speeding at 16,000 miles per hour at crystals coated with a thin layer of iron. For less than a millionth of a second, the bullets' impact nearly recreated the enormous pressure of molten iron at the center of the earth. With these measurements, the research team estimated that the temperature of the earth's inner core was about 12,000 degrees Fahrenheit — hotter than the surface of the sun.

In past years, Ahrens and his group have used the guns to compress the gemstone garnet into a crystal structure never before seen; fired bullets at hydrogen targets to simulate the environment deep inside Jupiter and Saturn; and found evidence for the hypothesis that a gigantic meteor hit the earth millions of years ago, perhaps leading to the extinction of dinosaurs.

# Bacterium Is Link to Past

Researchers have discovered in Thai rice paddies a bacterium whose ancient ancestors may have created the oxygen-rich atmosphere that sustains life on earth. The microbe, known as *Heliobacillus mobilis*, belongs to a recently discovered group of bacteria called Heliobacteria.

Heliobacteria respond to light and contain a form of chlorophyll which is intermediate to that found in green plants and cyanobacteria — the first bacteria to release oxygen on earth. Current theory holds that early forms of cyanobacteria used energy from sunlight to transform the earth's atmosphere into an oxygen-rich blanket suitable for animal life.

Structural similarities between cyanobacteria and *Heliobacillus mobilis* were only one clue that led an Indiana University research team to suggest that the newly discovered microbe could be the direct descendant of the ancient bacterium that produced cyanobacteria.

Further evidence, according to biologist and research team leader *Howard Gest*, came from the comparison of molecules called ribosomal RNA that are found in heliobacteria and other microbes. Ribosomal RNA, which plays a crucial role in making proteins, has evolved slowly over the years. The type found in *Heliobacillus mobilis* closely matched the ribosomal RNA found in some older bacteria that do not respond to light, the team noted, yet the RNA was strikingly different from that residing in other, more common light-sensitive bacteria. The new bacterium, related to both cyanobacteria and older, more primitive microbes, seemed clearly marked as an evolutionary link.

In addition to its evolutionary significance, the bacterium may also be useful as an efficient nitrogen fertilizer. Unlike other types of bacteria that convert nitrogen into a form useful for plants, heliobacteria live independently and do not attach themselves to a host plant for survival (as do the more common *Rhizobium*, now under intense study in genetic engineering labs). And the particular heliobacteria found in the Thai rice paddies "fix" or convert nitrogen to a useful form 10 times faster than do any other heliobacteria known.

FR Turner, Indiana University, Bloomington

**Soil research. Scanning electron micrograph shows *Heliobacterium chlorum* cells. This is a slow-moving bacterium isolated from the soil at Bloomington, Indiana. (Bar equals 5 micrometers.)**

FR Turner, Indiana University, Bloomington

**Evolutionary link. Electron micrograph depicts a single cell of *Heliobacillus mobilis*, a bacterium isolated from Thai rice paddy soil. It swims fast by means of hair-like flagella and may be closely linked to the ancient organisms that provided the oxygen-rich atmosphere for life on earth.**

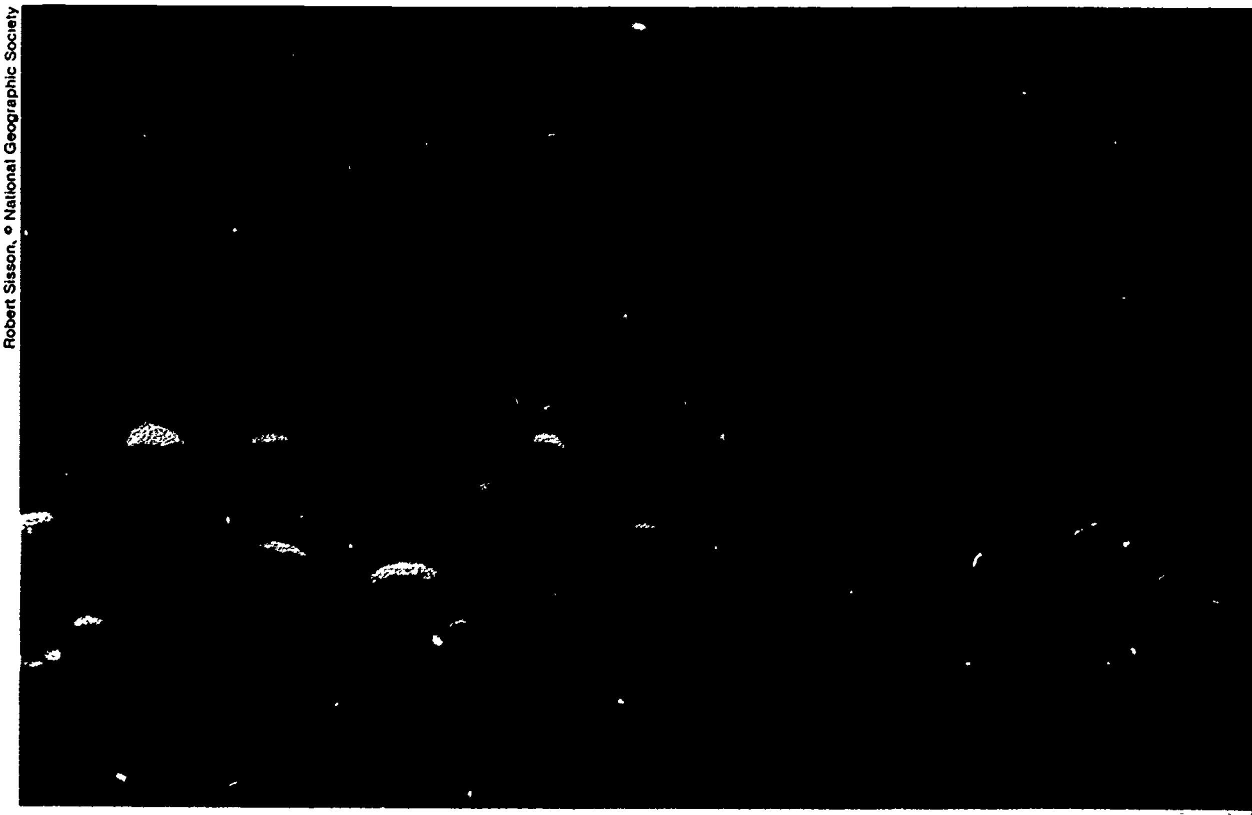
# Marine Life Research May Yield Insight into Brain Function

Researchers *Daniel* and *Aileen Morse* at the University of California at Santa Barbara have discovered that some red algae produce chemical signals that regulate metamorphosis of the marine mollusk, the abalone, from its larval stage to its mature form (well known as a seafood delicacy). The chemicals produced by red algae are short chains of amino acids known as peptides. These algal peptides have also been shown to function in the mammalian brain by binding to receptor sites that normally respond to GABA (gamma amino butyric acid), a hormone-like chemical involved in transmission of signals between nerve cells. The red algal peptides actually bind to brain receptors for GABA 100 times more tightly than does GABA itself. Conversely, GABA functions similarly to the algal peptides in stimulating the metamorphosis of the abalone larvae.

These biochemical findings are being used by hatchery owners to increase the supply of abalone by enhancing the conversion of larvae to edible adult animals. The information will also lead to a better understanding of the role of chemical signals in reef formation and how the hulls of ships become coated by marine organisms. Such findings also have potential for creating new probes to study the central nervous system. Researchers studying the binding ability of the algal peptides to GABA receptors in the mouse brain hope to learn about the interaction of the peptides and the receptors. In the future such peptides may be used to develop new, more specific drugs for treating GABA-related brain disorders.

**Receptor recognition of an environmental signal. In this lab experiment, abalone larvae capable of undergoing developmental metamorphosis have recently settled, and are browsing upon, a red algal surface. The larval surface receptors controlling the events of metamorphosis have been activated by contact with unique peptides at the alga's surface.**

Robert Sisson, © National Geographic Society



Robotics. Michael Mulder (right) and Neldon Wagner are seen with the two-legged robot they designed at Oregon's University of Portland.

A research team at Oregon State University has studied the leg motion of insects to help lay the foundation for developing the next generation of walking robots and remote-control moving equipment. According to engineer *Eugene Fichter*, who collaborated on the study with his wife, entomologist *Becky Fichter*, "Insects are magnificent models for walking machines" because of their variety of walking styles and the types of surfaces they travel on. Surfaces insects walk on range from smooth to bumpy, vertical to horizontal, and solids to webs. Some insects walk slowly, while others run rapidly and jump many times their body length.

This type of versatility must become part of the design of walking robots if machines are to achieve the capabilities of animals. Studying spiders or other web-walking insects, for example, could teach important lessons on how inspection machines might crawl between the walls inside a nuclear reactor building or how robots could climb the steel frame of a building under construction. Present walking machines have had some success as engineering models, but their movements are limited.

While other researchers have analyzed the gait of insects to investigate how their feet may be used as sensors, there have been no previous detailed studies of the way insect legs move or how their leg structure limits possible movement. The insect study, an ongoing project, is conducted by recording movement on film, video recorder, and computer vision systems. A computer compares the movements actually taken by the animal with theoretical limits assumed by engineering mechanics. The researchers have measured leg segments, identified types of joints, and studied the way adjacent joints are arranged.

This research effort, which also included Oregon State mechanical engineer *Stephen Albright*, is funded by an experimental program within NSF's engineering division that seeks out creative and novel engineering ideas not being exploited (see chapter 2 for more description).

At Oregon's University of Portland, scientists have taken a different approach to understanding the challenges of controlling complex machinery. The Portland team, headed by *Michael C. Mulder* and senior researcher *Neldon Wagner*, used a two-legged walker that can balance only while moving. The walker relied on an innovative gyroscope-like device to keep its balance, as well as a multiple computer system and sensors to measure its position and adjust for varying terrain. A special hydraulic engine shifted weight from one leg to the other as needed, according to computer instructions.

The multiple computers, known as a parallel processing system, allow the walker to make several decisions about moving swiftly and simultaneously, more akin to the action of the human brain than computers which process information step by step.

In practice, a sensor similar in function to a gyroscope detects how far the walker is leaning over, other sensors in the legs and "feet" monitor the angle of joints and the hardness of the ground. The information is fed back 500 times a second to a computer, which compares the actual position of the robot to a computer model and makes adjustments for the difference by regulating balancing fluid in the legs of the walker. Rather than aiming to create the perfect walking robot, the research team views the walker as a means to learn more about sensor-based control of complex machines.

Infant imitation of adult behavior has long been recognized as playing a crucial role in the social and cognitive development of children. But until recently, scientists believed that infants could not imitate facial gestures until they reached about one year of age. Developmental psychologist *Andrew N. Meltzoff* and his colleagues at the University of Washington demonstrated, however, that babies who were only 12 to 21 days old mimicked such gestures in adults as sticking out a tongue or protruding the mouth or lips. The youngest baby to mimic the gestures was only 42 minutes old.

The research team also found that infants ranging from 14 to 24 months could recall and imitate an adult activity an entire day after observing the action. Infants who watched adults dismantle and reassemble a dumbbell-shaped toy mimicked the action a day later, even though they had never before touched the toy.

According to Meltzoff, the findings demonstrate that "from the earliest stages, even before they acquire language, infants are exquisitely sensitive to adult actions, and [this] indicates the profound influence that these observations can have on the infant's subsequent behavior."

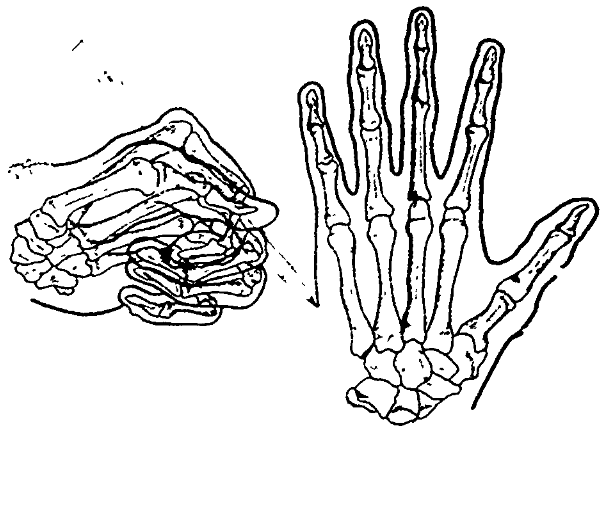
**Infant imitation. Photographs from videotape recordings show that infants only two to three weeks old imitate the mouth movements of adults.**

Across the country during early April 1987, thousands of schools, community groups, science organizations, museums, and government agencies devised creative ways to focus attention on the role that science and technology play in daily life. Begun in 1985 by NSF, National Science and Technology Week seeks to increase the public's awareness about science, engineering, and mathematics and to encourage young people to consider careers in these areas.

A special feature in 1987 was "The Art of Science" competition, in which high school seniors nationwide contributed paintings, photographs, and other artwork dealing with some aspect of science or technology. Among the winners was *Seong Kim*, from the Bronx (NY) High School of Science. His ink drawing depicted the outline of a hand, showing every bone, in the process of sketching the outline of another skeleton-like hand. *Wendy Brill* at Westlake School in Los Angeles contributed a hand-tinted photograph of open-heart surgery; *Ellen Dare Safrit* at the North Carolina School of Science and Mathematics in Durham won for her silkscreen printing that depicted the cell structure of plant stems. The silkscreens were based on cell photographs that Safrit had taken through a light microscope.

Commented Safrit, "Complex scientific equipment combined with modern photographic and silkscreening processes have given artists the ability to capture nature's inherent beauty and creatively display the 'art of science.'" The exhibition of winning artwork, co-sponsored by NSF and the New York Academy of Sciences, has travelled throughout the United States.

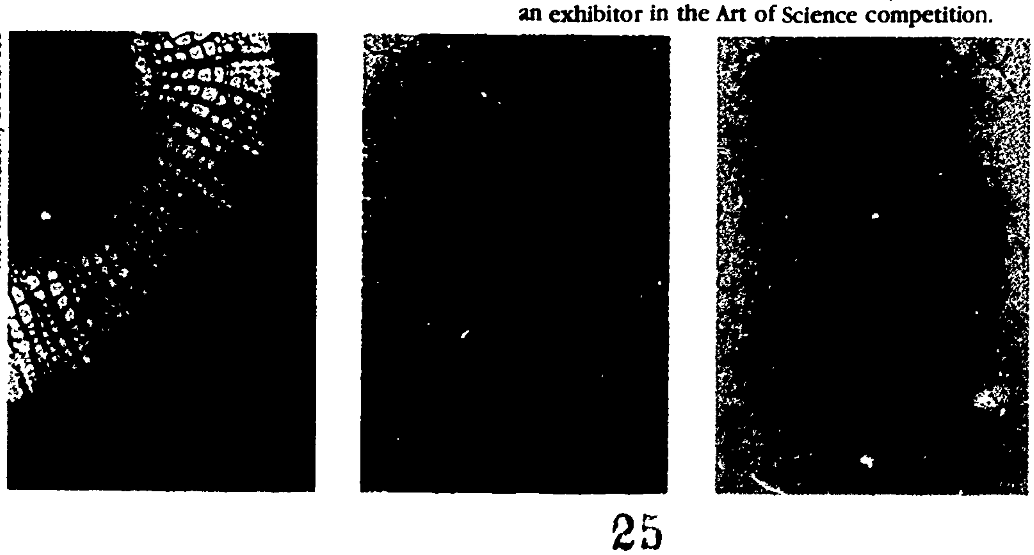
**Art exhibitor. Seong Kim at the Bronx High School of Science in New York turned the bone structure of the human hand into a work of art with "Hand: The Ultimate Tool."**



New York Academy of Sciences

**Art of science. Ellen Dare Safrit at the North Carolina School of Science and Mathematics used microscope photographs of plant stems to create "Botanist's Cathedral," a photographic silkscreen print. She was an exhibitor in the Art of Science competition.**

New York Academy of Sciences



More than 30 years after his death, Princeton University Press has published the first volume of Albert Einstein's papers. The papers track the thoughts of Einstein as a young man through 1902, and include letters detailing his early views about physics and the beginnings of his thoughts about relativity theory. Other letters are an account of Einstein's fruitless search for a university position—a search that finally led him to accept a job at the Swiss patent office, where in his spare time he was to develop his Special Theory of Relativity.

The documents, commented science historian Gerald Holton, portray "a mind sharpening its tools, a young man of 22 beginning to ask fundamental questions, an intellectual giant." Publication of the volume was made possible in part by a $750,000 grant from NSF. A projected 40 volumes of Einstein's papers will be published over the next few decades.

**Please forgive a father who is so bold as to turn to you, esteemed Herr Professor, in the interest of his son.**

**I shall start by telling you that my son Albert is 22 years old, that he studied at the Zurich Polytechnikum for 4 years, and that he passed his diploma examinations in mathematics and physics with flying colors last summer. Since then, he has been trying unsuccessfully to obtain a position as Assistant, which would enable him to continue his education in theoretical and experimental physics . . .**

**My son therefore feels profoundly unhappy with his present lack of position, and his idea that he has gone off the tracks with his career and is now out of touch gets more and more entrenched each day . . . it is you to whom I have taken the liberty of turning with the humble request to read his paper . . . and to write him, if possible, a few words of encouragement, so that he might recover his joy in living and working.**

**If, in addition, you could secure him an Assistant's position for now or the next autumn, my gratitude would know no bounds.**

Hermann Einstein to
Prof. Wilhelm Ostwald,
1901

Joyce Latham

**Einstein statue at the National Academy of Sciences, Washington, DC**

# "3-2-1 Contact" Goes to Antarctica

In the fall of 1987, crew members from a major science show on television visited the coldest continent and filmed major program segments. The show was "3-2-1 Contact," seen on public TV and produced by the Children's Television Workshop in New York City. "Contact" is aimed at young people (ages 8 to 12) and partially funded by NSF. During the show's visit to Antarctica, the four crew members stayed at NSF's McMurdo Station, with a further trip to the geographic South Pole. They filmed segments on such topics as the antifreeze properties of antarctic fish; ongoing studies of the local seal population; the geology and glaciology of the extraordinary antarctic landscape; and the monitoring of ozone levels in the upper atmosphere. The visit will result in a week's worth of antarctic stories scheduled to air on PBS in the fall of 1988.

In addition to the "3-2-1" visit, Cable Network News (CNN) also filmed major program segments in Antarctica in late 1987.

***3-2-1 Contact*** **in Antarctica. The TV crew poses in front of Shackleton's Hut, where explorers rested during their investigations of Antarctica in the early 1900's.** ***3-2-1*** **is supported in part by NSF.**

Penguin research. Debra Shapiro, cast member of *3-2-1 Contact*, feeds penguins in preparation for a diving study. At right is Scripps Institution zoologist Gerald Kooyman.

# Life Saver

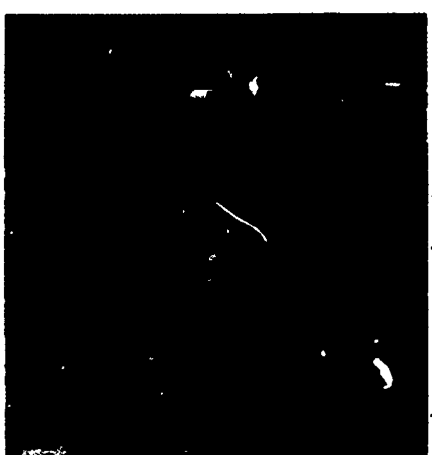
An NSF Small Business Innovation Research (SBIR) grant was instrumental in developing a high-pressure water drill that helped save a life in October 1987.

World attention was focused on 18-month-old Jessica McClure, trapped inside a well in Midland, Texas. When other oil-drilling equipment—including a diamond drill—failed to rescue her, a special water-powered drill was rushed to the scene. The drill, which sprays a fine, high-pressure jet of water at 2,900 feet per second (two to three times the speed of a bullet), slices through rock quickly by eroding the surface. In just two hours, the drill had cut a hole two feet in diameter through three feet of extremely hard caliche limestone rock, where the baby was trapped in the well shaft. An hour later, the child was free.

The special drill was supplied by ADMAC, a spinoff of Flow Technology Company of Kent, Washington. Flow Technology, a minority-owned firm, received an NSF grant in 1980 for research on the high-pressure water drill, a tool with a novel design that had at first been greeted with skepticism. While further development and financing were required to commercialize the drill, the NSF-funded research initiated the innovative technology and encouraged the company to continue its efforts.

Flow Technology has received other SBIR grants in the field of abrasive metal cutting, surface materials, and robotics. The company has leveraged this research support to market commercial products.

For more on SBIR grants, see chapter 3.



**Life-saving equipment. An ultrahigh-pressure pump and jet lance, similar to what is shown here, powered the waterjet rock-cutting system used to free Jessica McClure from a well in Midland, Texas. NSF was instrumental in early funding of the research that produced the ultrahigh-pressure nozzles and related technology used in the rescue. Second photo shows pump that is inside large box.**

# CHAPTER 1

# INTO THE 1990's

Natural curiosity — the unwavering instinct to know how and why — is often the driving force behind basic research in science and engineering. But from Isaac Newton's discovery of the universal law of gravitation to the wonder of the Wright brothers' triumphant liftoff at Kitty Hawk, the study of science and engineering has done more than merely satisfy the intellect. Efforts in science and engineering improve our economic competitiveness with other countries, provide better health care for the nation, and form the basis of our national defense.

Against this backdrop, the mission of the National Science Foundation is indeed a challenge. For among all federal agencies, it is the Foundation's charge to promote science and engineering in general and support basic research across all fields and disciplines.

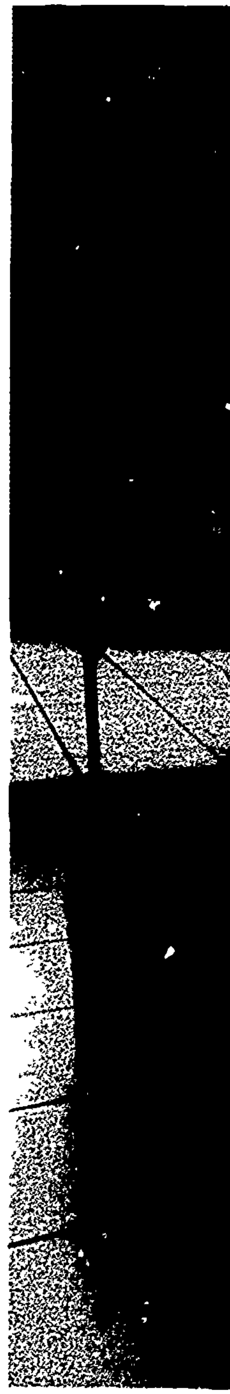
In 1987, NSF focused on several new issues and continuing concerns:

• **Economic Competitiveness.** In 1987, the need for the United States to compete in the world marketplace received new recognition. Revolutionary findings in superconductivity research highlighted the vital link between science and technology in creating new and competitive products. Moreover, mounting trade deficits with foreign nations, concern over inroads made by Japan and other countries in producing new technologies, and a shrinking supply of American college students pursuing science careers spurred action by the President, private groups, and Congress.

In the U.S. Congress, the Senate and the House of Representatives established a joint, bi-partisan Caucus on Competitiveness to formulate new legislation. Among two new private groups, the Council on Competitiveness examined issues ranging from ways to decrease the trade deficit to increased support for NSF; the Council on Research and Technology, a group whose members include universities and private research firms, began to study national R&D policy.

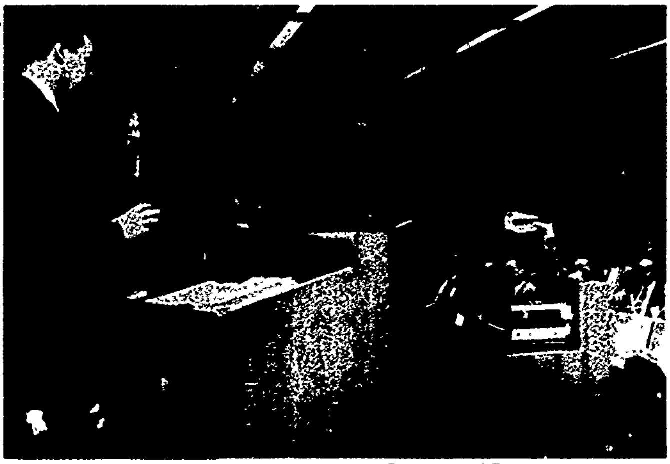
For its part, NSF embarked on a joint effort with the National Governors' Association and the Conference Board, a national organization of business groups. Together they examined the way economic competitiveness is perceived at the state level by industry, universities, and state officials. This activity had two components: a national survey, followed by regional discussion forums.

The survey identified several areas in which the United States must increase its investment in order to remain competitive. These include science and mathematics education, university/industry cooperative ventures, and greater commercialization of research findings. Moreover, these investments should be long-term, the survey report said.



**Present and future tools.** Supercomputers will continue to be valuable scientific tools. This Cray supercomputer is at the University of Illinois.

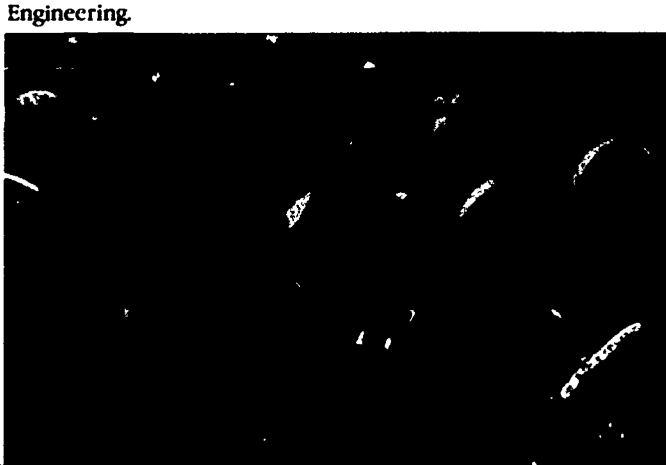
Star Ledger



State partner. In April 1987 New Jersey Governor Thomas H. Kean spoke at a regional conference at the AT&T Bell Laboratory in Holmdel, N.J., on the role of science and technology in economic competitiveness.

Presidential visit. President Reagan watches robotics demonstratioı. at the NSF-suppcrted Engineering Research Center at Purdue University.

Purdue welcome. At Purdue University's Engineering Research Center, the President shakes hands with Henry Yang, Dean of Engineering.



Along with these efforts, NSF also launched a pilot project to strengthen communication links with states. Initial efforts focused on four states in particular: Michigan, New Jersey, Arkansas, and Utah.

Focusing on the state level has provided better understanding of state policies and activities supportive of science and engineering research and education, and identified points of common interest with NSF. The states initiative also gave NSF a first-hand look at how the states are working with universities and industry to link research and education with their plans for economic development. This initiative is described further in chapter 2.

Also at the state level, NSF continued its Experimental Program to Stimulate Competitive Research (EPSCoR), begun in 1979 to aid states that lack large resource bases for research. A recent EPSCoR grant to the University of Alabama at Huntsville supported breakthrough research in superconductivity (see "Highlights" section).

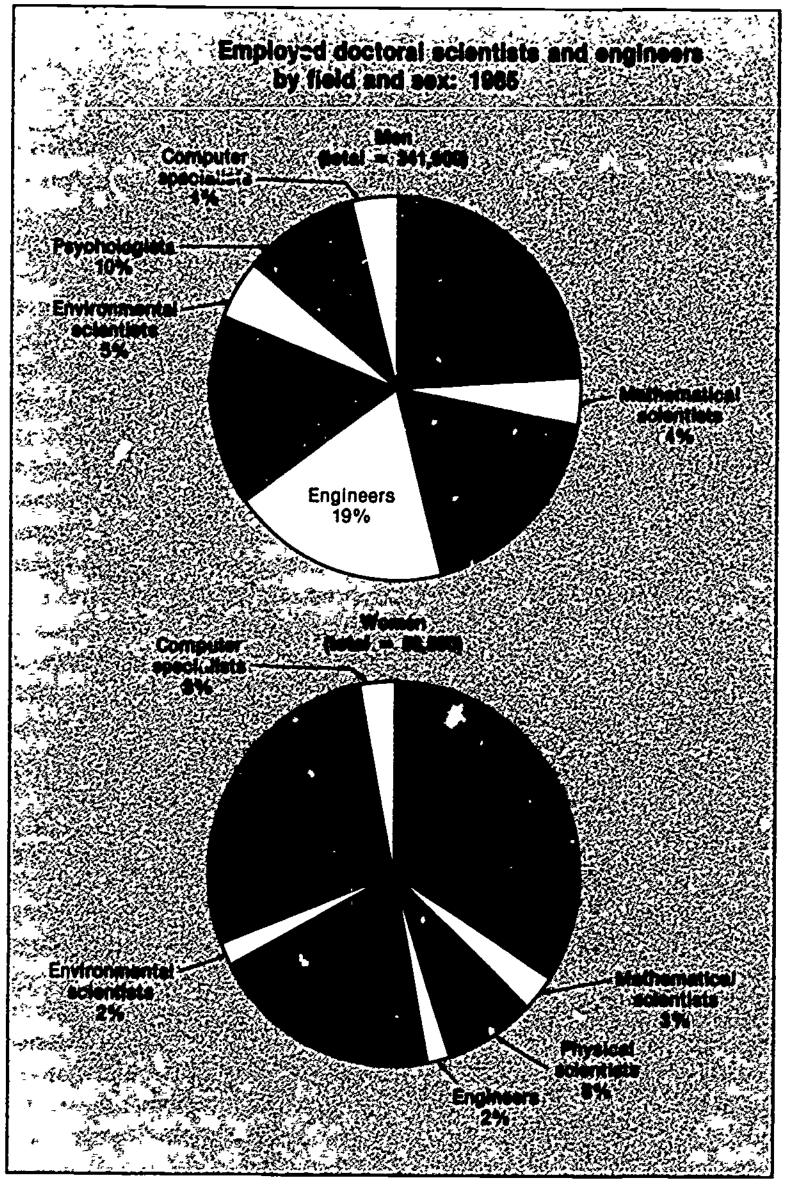
- **Growing Emphasis on Interdisciplinary Research.** Some of the most significant problems in basic research are at the boundary between established disciplines. For example, advances in biotechnology, materials research, and information science depend on scientists and engineers with a variety of disciplinary skills, and research environments that encourage new types of collaborations. Recognizing this, NSF extended the number of its Engineering Research Centers, which stress an interdisciplinary approach, to 14 as of late 1987 (See chapter on centers and groups). In addition, NSF initiated a new centers program in biology; awards totalling $10 million for laboratory equipment resulted in "mini-centers" for biology at 20 campuses. And the Foundation began a program called Opportunities for Research in Computational Science and Engineering. This effort encourages the use of advanced computing techniques in collaborative research among mathematicians, engineers, physicists, chemists, and other scientists.

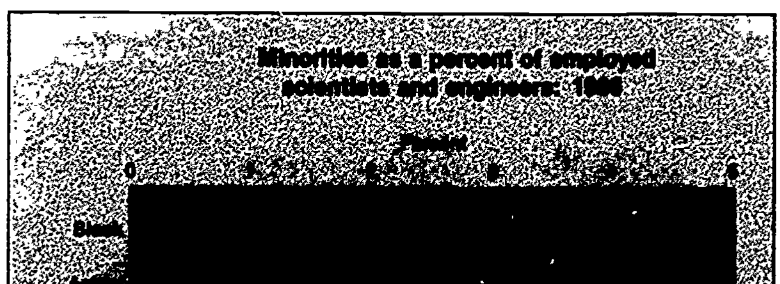
- **Expanding Human Resources.** Important parts of NSF's mission are to encourage young people in science education and to help ensure that talented women and members of minority groups are exposed to science and engineering careers and attain positions commensurate with their abilities. Faced with current faculty retirement rates* and the continuing decline of 22-year-olds — the main group from which future scientists emerge — increased participation by women and minorities may be a key way to avoid a future shortfall of scientists and engineers.

To assess the current status of women, minorities, and disabled persons in the sciences and develop long-range plans to advance their opportunities, the federal Office of Science and Technology Policy** appointed a new interagency task force in FY 1987. Members of the Task Force on Women, Minorities, and the Handicapped in Science and Technology are from NSF and other federal agencies concerned with R&D issues, private business, academia, professional associations, and nonprofit groups. They will report on their findings on or before December 31, 1989.

*A large segment of faculty will reach retirement age during the next five years, especially in civil and electrical engineering, physics, mathematics, and economics. See NSF Highlights No. 87-310, *Recent Doctorate Faculty Increase in Engineering and Some Science Fields* available from NSF, Division of Science Resources Studies, 1800 G St. NW, Washington, DC 20550.

**OSTP is headed by the President's Science Adviser.



Source: *Women and Minorities in Science and Engineering,* Jan. 1988, NSF 88-301

Another group, the Congressionally appointed Committee on Equal Opportunities in Science and Engineering (CEOSE), currently advises NSF on ways to boost the participation of minorities, women, and disabled people in scientific and technical careers. In a 1986 report, CEOSE praised many ongoing and new NSF efforts to promote equal opportunity, including awards in engineering for disabled, minority, and women researchers; Visiting Professorships for Women; and grants for minority researchers and minority institutions. At the same time, CEOSE recommended that Congress reevaluate the need for a number of programs that NSF discontinued in the early 1980's, including Student Science Training programs.

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**We must significantly increase minority participation in science and engineering. And we must do so not just for reasons of equity, although equity is clearly a fundamental concern. The reasons are just as much related to national need and the challenge to our economic competitiveness.**

—John H. Moore, NSF Deputy Director (speech to White House Conference on Historically Black Colleges and Universities, Sept. 1987)

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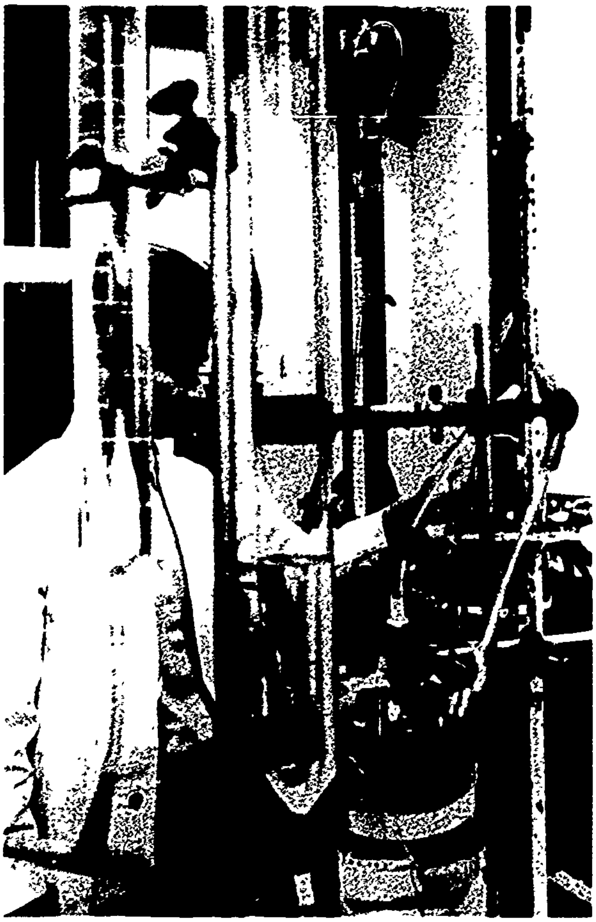
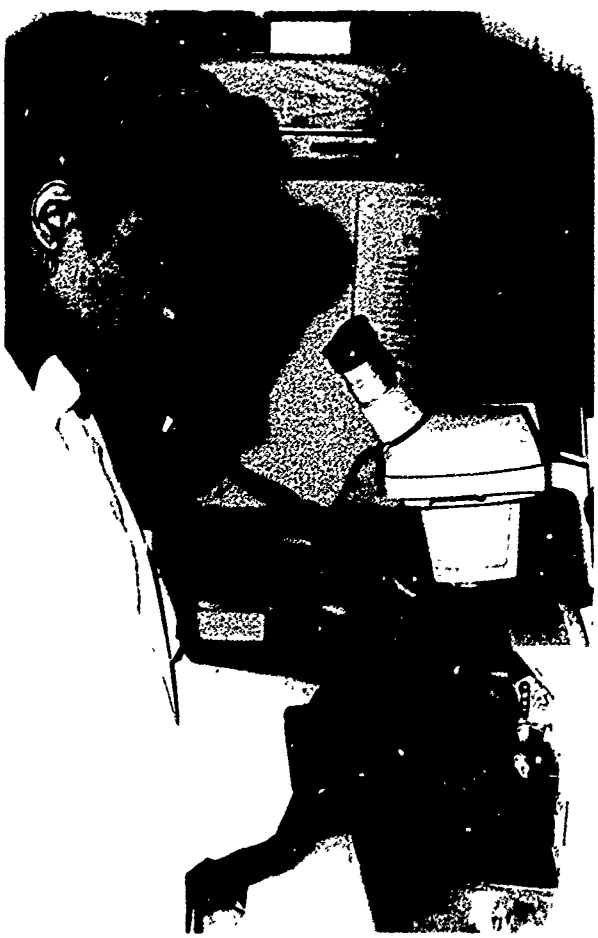
During 1987, NSF also bolstered its long-term commitment to science education. For example, the Foundation launched a major new effort to upgrade the science curriculum from kindergarten through grade 12. At the college level, NSF began a program to



Johns Hopkins Magazine

Working woman. Increased participation by women and minorities in basic research may be crucial to avoiding a future shortfall of scientists and engineers.

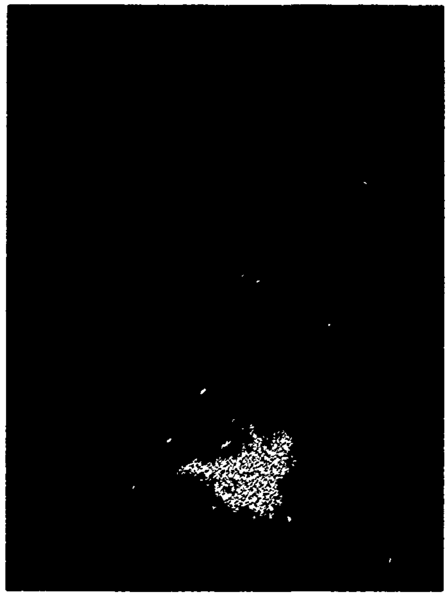


Future scientist at work

give students, while still undergraduates, the opportunity to conduct research in science and engineering Projects involving women, minority students or persons with disabilities are given high priority for support. And another NSF initiative in 1987, "Awards for Creative Engineering," gives research grants to engineering undergraduates and recent graduates based on creative ideas submitted in a research plan, rather than judging them solely on their academic record. See chapter 2 for more on these and other human resources efforts.

• **Continuing Issues.** Boosting support for basic research remains the Foundation's key priority. In the 1970's basic research gave us a rapidly developing biotechnology industry and taught us how to design high-speed supercomputers. And research dating back to 1911 paved the way for the recent technological breakthrough in superconductivity.

The challenge for NSF is twofold. At a time when the need for basic research is greater than ever, funding for academic R&D may have to double over the next decade just to maintain activities at current levels. Increased funding, ongoing NSF support of collaborations between universities and industry, continuing international cooperation and exchange of ideas, and the sharing of expensive equipment at universities may help smooth the road ahead for campus research.



**Biotechnology—another face of science in the 1990's. Here a tobacco plant's genetic makeup was altered by introducing a firefly gene into the plant's DNA.**

Children's TV Workshop

**Science as fun—early exposure in the classroom**

34

CHAPTER 2

# HUMAN RESOURCES AND EDUCATION

**Education is the great American adventure, the largest public enterprise in the United States, the country's most important business.**

— Mary McLeod Bethune

Boosting the scientific and technical education of our nation's young people is one of the National Science Foundation's major responsibilities. Although NSF funds graduate-level education, supporting students who will become Ph.D. scientists and engineers, the Foundation also has programs at the elementary, secondary, and undergraduate levels. These efforts help to strengthen the quality of instruction in the sciences and mathematics.

In addition, NSF is committed to increasing the number of women and minorities in science and engineering careers, a goal that may be crucial to bolstering our economic competitiveness with other countries. NSF data show that employment of scientists and engineers grew three times as fast as total U.S. employment over the past decade, yet the proportion of college seniors who majored in the sciences is smaller today than it was in the 1970's. Efforts to attract a larger share of women and minorities in science classes and careers may help to compensate for a projected shortfall of scientists and engineers.

As part of a federal interagency task force set up in 1987, NSF has studied the role in science of women, minorities, and people with disabilities, considering new ways to advance their opportunities. NSF efforts in this area may never have been more urgent: the American Council on Education has termed declining college enrollments among Blacks a "national crisis," and the gains of women in science and engineering over the past 15 years now appear to be slowing, according to a special issue of NSF's *Mosaic* magazine, "Education and the Professional Workforce."*

Some NSF responses to the nation's human resource and educational needs include these activities:

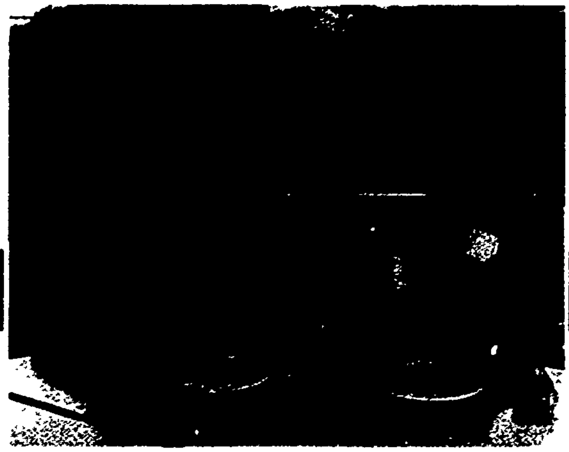
## PRECOLLEGE EDUCATION

There once was a time when the absence of a high school diploma and basic skills was not an obstacle to employment in certain occupations. Now those occupations are disappearing. Employment in the modern world increasingly demands basic literacy in science and mathematics. Yet nearly 30 percent of the nation's high schools offer no courses in physics, 17 percent none in chemistry, and 70 percent none in earth or space science.

The vast numbers of high school students take few mathematics or science courses. In comparative tests in subjects such as geometry, U.S. students were outscored by those of other

**Mosaic*, Spring 1987, Vol 18, No 1 (See article on "Women's Progress," by Betty M. Vetter, p. 2)

Early Learning Co



Early learning about science

nations and often placed last. One recent international study* found that U.S. elementary and high school students, especially girls, know less about science than their counterparts did in 1970. Moreover, they lag behind British and Japanese pupils in physics, chemistry, and biology.

In short, too much of the population is unprepared to function productively in our increasingly complex and technological world. A survey conducted for the NSF in 1986** found that large numbers of Americans do not understand basic scientific terms such as "molecule" and "radiation." As NSF Director Erich Bloch has commented, "What is at issue here is not lack of interest; it's lack of opportunity. More explicitly, it is a lack of quality in the institutions on which we depend."

**On display.** Seventh- and eighth-grade students from Lincoln Park Community School in Somerville, Massachusetts show off their science project at Lesley College. Lesley is one of several colleges and universities that have received NSF grants to improve middle school science and mathematics teaching.

**The shape of things.** Portland State University's Marjorie Enneking (center) discusses ways to teach geometry with prospective middle school math teachers Sandra Sump (left) and Anne Ryan (right).

## Curriculum Grants

In its continuing effort to improve that quality, NSF's Directorate for Science and Engineering Education announced in 1987 a new program to greatly expand and upgrade science education in grades kindergarten to 12 over the next four years. The new NSF program, which began with three curricula grants totalling $6.6 million, emphasizes student participation in science experiments and seeks to relate lessons from other subjects — language, arts, and mathematics — to science.

For example, instead of demanding that young children memorize facts about acids, one of the NSF curricula grants encourages students to learn the concepts by studying acid rain, collecting rain in their backyards and measuring its acidity. In conjunction with the National Geographic Society, this grant supports children at 4000 schools nationwide as they collect and enter information on a central computer, which enables them to compare and compile within days data from across the country.

A novel feature of the program is that each of the four-year curricula grants is matched by publishers who work with the schools to develop and test new teaching materials, then train teachers to use them. The early involvement and commitment by publishers help to ensure that the course plan designed by researchers will actually be adapted for everyday use in the classroom. Publishers, which include the National Geographic Society and the Kendall/Hunt Publishing Company of Dubuque, Iowa, will devote 5 percent of their revenues from sales of the printed curriculum to teacher training and support.

## Improving Middle School Teaching

NSF also awarded grants to nine universities and colleges to improve programs to prepare middle school teachers in science and mathematics. The goal of this NSF program is to foster a close collaboration among

Rose Nichols

**Hands-on experience.** Amy Barber, a middle school math and science teacher, discusses a science project with a student. They are attending a special evening program at Lesley College in Cambridge, Massachusetts.

*The International Association for the Evaluation of Educational Achievement, located at Columbia Teachers College in New York City, based these findings on research done in 1983 and 1986.

**See *Science and Engineering Indicators — 1987* (National Science Board, 1988).

science professionals, university faculty, and school personnel in developing model courses for training elementary, middle, and secondary school science and mathematics teachers.

Each of the nine projects includes special features. For example, the NSF grant to Lesley College, a college for women, focused on attracting women to teaching careers in mathematics and science. And a grant to Oregon's Portland State University developed a model to prepare math and science teachers in urban schools.

## Private Sector Partnerships

To improve science and mathematics education in grades kindergarten to 12, this program encourages partnerships between business/industry, school systems, and other educational institutions. The overall aim here is to demonstrate ways in which community concerns can be translated into positive action to improve the quality of science and math education in American elementary and secondary schools. This program seeks to generate novel approaches and models in such areas as teacher enhancement, teacher preparation, education networks, research in teaching and learning, instructional materials development, informal science education, and applications of advanced technologies.

## Summer Programs for Chemistry Teachers

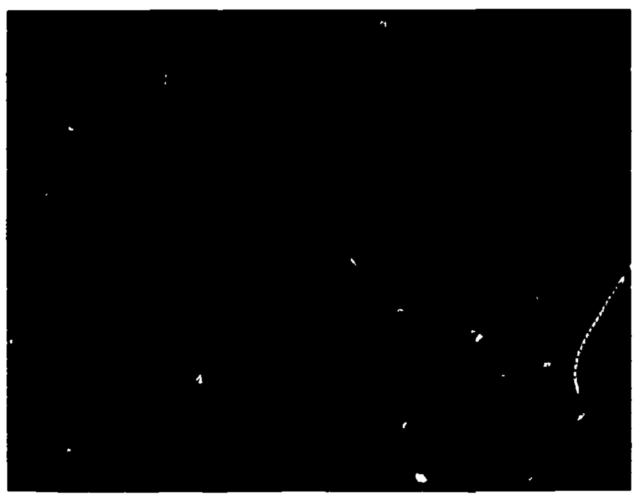
Updating the skills of experienced teachers and strengthening the science background of new faculty can spark new enthusiasm for science teaching. Through special summer programs at five sites,* the NSF-initiated and supported Institute for Chemical Education (ICE) seeks to improve chemistry teaching at the middle and high school levels.

* The University of Arizona at Tucson, the University of Northern Colorado at Greeley, the University of Wisconsin at Madison, the University of Maryland at College Park, and the University of California at Berkeley.

**Private sector partnerships. A high school teacher and an industry scientist explore polymer chemistry at an NSF-sponsored summer workshop at the DuPont Company Experimental Station in Wilmington, Delaware.**

The program has three main activities: a six-week course upgrades the skills of high school science teachers assigned to teach chemistry but lacking a strong background in the field. Another summer course prepares middle and senior high school teachers to use demonstrations and laboratory equipment in chemistry courses, helping to enliven and underscore the lessons students learn in lectures. A third course updates the knowledge of experienced high school chemistry teachers in selected topics.

Math teacher. New Hampshire's Timothy Howell won a Presidential Teaching Award in 1984.



## Support for Mathematics Education

As part of its commitment to excellence in mathematics education and curriculum development, NSF supports efforts of the National Research Council in these areas. In October 1987, the Council's Board on Mathematical Sciences and the Mathematical Sciences Education Board, both funded by NSF, held a highly publicized symposium on methods to improve the teaching of calculus. Although current methods of teaching calculus have been criticized, this branch of mathematics remains indispensable for physics, engineering, and many other sciences.

The symposium, sponsored by the Alfred P. Sloan Foundation, helped to focus public attention on the importance of integrating new approaches in teaching mathematics. Through its continued support of the Council's mathematics boards, NSF hopes to play a significant role in upgrading mathematics teaching and encouraging younger students to take mathematics courses.

## Presidential Awards for Science and Mathematics Teachers

(See later chapter on awards )

## Minority High School Students: Research Assistantships

Exposing minority students early on to the challenges and rewards of research may encourage them to choose science careers, strengthening the nation's human resource base. In 1987, the Foundation began providing supplemental funding to NSF principal investigators who wish to include minority high school students as assistants in their research projects Each student research assistant then submits a one-page report summarizing the nature and results of his or her participation in the research project.

## Special Partnerships

In addition to its support of education programs across the nation, NSF has had special partnerships with certain schools in the nation's capital. In 1982, for example, parents of students at Anne Beers Elementary School in southeast Washington, D.C. were alarmed that declining enrollments

NSF partners—students at Anne Beers Elementary School in Washington, D.C.

might force the school to close. They asked local education officials to develop a new program to attract students and keep the school up to date. The result was NSF support for a modern science laboratory where students could investigate such questions as how plants grow, measure the length of shadows to calculate solar time, compute the slope on the playground, and understand how magnets attract. The Neighborhood Advisory Commission donated money and office equipment, the local Parent-Teachers Association painted walls and helped to install floor coverings for the science laboratory.

Recent test scores at the school have shown improvement in science as well as other subjects since the NSF-sponsored project began. Science is now taught at the school for a full hour each day, rather than the usual 45 minutes every other day.

NSF also has a special partnership with another school in Washington, D.C.—Banneker High School. Since 1982, NSF has worked with teachers to strengthen the math and science curriculum at the school. The Foundation provides speakers on science topics covered in the classroom and sponsors an annual Math and Science Day. Student winners of an annual math/science exam sponsored by NSF (held in conjunction with National Science and Technology Week) visit a major NSF-supported facility; in 1987 the top students toured the Kitt Peak National Observatory in Arizona. In addition, the Foundation in 1987 gave Banneker a $2000 grant to upgrade its biology laboratories.

## UNDERGRADUATE AND GRADUATE EDUCATION

With the baby boom over, the number of 22-year-olds—the main source of new scientists and engineers—continues to decline. Several recent NSF initiatives complement older efforts to encourage college students in research careers, helping to ensure an adequate supply of engineers and scientists for the future.

### Research Experiences for Undergraduates

This program gave some 2000 students in 1987 the chance to participate in science and engineering research projects on campus, in industrial or government laboratories, or at other nonacademic institutions. Projects that include female, minority, or disabled students as researchers are given high priority.

Among the activities that received funding was a joint venture between three American universities and the University of Tarapaca in Chile. Eight U.S. students travelled to the Atacama Desert in southern Peru and northern Chile to study paleonutrition, the diet and well-being of past civilizations. The students examined several hundred mummies and skeletal remains in an effort to reconstruct diets, diseases, vitamin deficiencies, and general living conditions in the area over the past 8000 years.

In another project, East Carolina University devised a summer research program for students with hearing, visual, and mobility disabilities. In addition, the university arranged a series of lectures by successful scientists who have handicaps.

### Awards for Creative Engineering

A new NSF program awards research grants to undergraduate engineering students and recent graduates based on innovative ideas submitted in a research plan, rather than solely on their academic record. Among the 1987 award winners was *Tracy Rubin*, a Tufts University senior who was accepted for graduate study at Tufts in bioengineering/chemical engineering. Rubin's grant enabled her to conduct research on the development of vaccines that could be produced at small factories.

### Fellowships

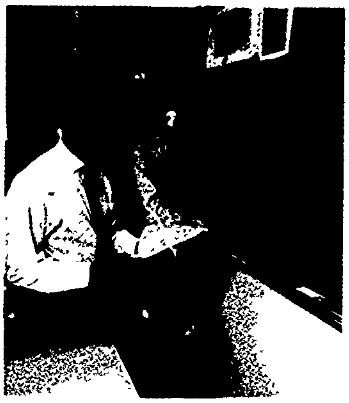
Through two long-standing NSF programs—Graduate Fellowships and Minority Graduate Fellowships*—outstanding students are awarded annual stipends to pursue graduate study in science and engineering. A new feature was added to the minority fellowship program in 1987. For the first time, the undergraduate departments of colleges where award winners studied were honored with $1000 Incentives for Excellence Prizes, in recognition of faculty efforts to identify and support the work of students.

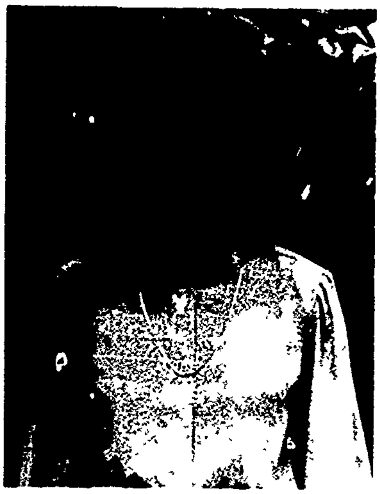
## OTHER ACTIVITIES

NSF also seeks to develop a cadre of talented scientists and engineers by selecting promising young faculty for its Presidential Young Investigator (PYI) Awards, instituted in 1985. In 1987, 200 young faculty members, the majority of them in physical sciences or engineering, received the awards, given by NSF to help universities attract and retain outstanding young Ph.D.'s for academic careers. Among the 1987 recipients was *Denise Denton*, an electrical and computer engineering professor at the University of Wisconsin at Madison. Her research has focused on the electrical properties of polyamide, a material used in making integrated circuits.

*Some 24,000 Fellows have participated in these programs since 1952. Among them are 10 Nobel Laureates, 6 Field Medalists in mathematics, and 6 Waterman Awardees (described in a later chapter)

**PYI. Computer scientist Deborah Estrin, UCLA, is a 1987 Presidential Young Investigator. She comes from a family of engineers that includes her mother, Thelma Estrin, a former NSF division head in the Engineering Directorate.**





Minority Graduate Fellows. Louis Houston (left) and James Rice are former NSF Fellows. Both physicists, they are now researchers for the EXXON Corporation. Second photo shows Daphne Smith, a postdoctoral fellow in statistics at the University of California, Berkeley. She too is a former NSF Minority Graduate Fellow.

Award winner. Gerasimos Lyberatos specializes in biochemical engineering at the University of Florida at Gainesville. He was one of ? 0 scientists and engineers who received NSF's Presidential Young Investigator award in 1987.

NSF provides research support for PYI award winners at a minimum of $25,000 a year for five years. In addition, the Foundation also matches, dollar for dollar, contributions from industry for up to $37,500 a year.

A number of established NSF programs focus on minority and female scientists and those who are disabled:

- The Minority Research Initiation program helps minority faculty members obtain their first research grants through special assistance and funding.

- Under the Research Improvement in Minority Institutions program, NSF boosts the research capabilities of minority colleges and universities.

- Facilitation Awards for the Handicapped provide extra funding for special equipment or assistance that disabled scientists, engineers, or student research assistants need to participate in specific NSF research projects.

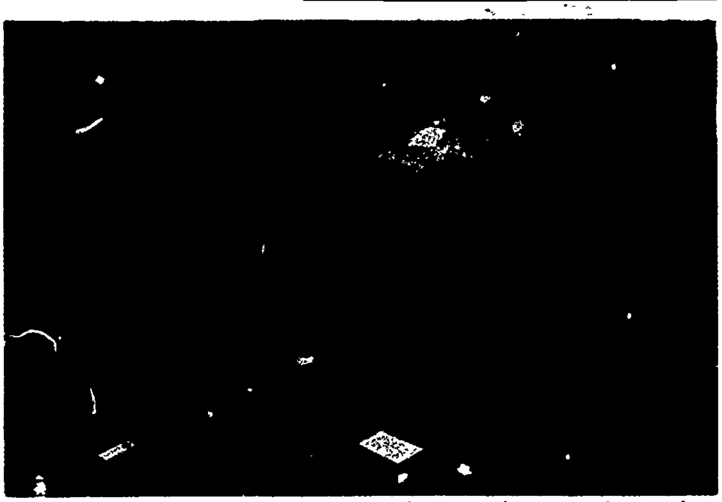
(In FY 1987 seven FAH awards were made. Five of them provided personal assistance for disabled investigators, one provided personal assistance for a disabled student research assistant, and one provied special equipment to enable two disabled students to work as research assistants. Disabilities included blindness, profound hearing loss, spinal nerve damage, arthritis, and multiple sclerosis.)

- The Research Opportunities for Women program offers research planning and initiation grants to female scientists who have not previously led research projects; the program also gives career advancement awards to more experienced female investigators.

- Visiting Professorships for Women provide grants for women scientists to spend from six months to two years at a host university of their choice. This NSF program has a twofold aim: helping women to further their science or engineering careers and encouraging other women to pursue such careers Mathematician *Priscilla Greenwood*, the only woman in a department of 80 at the University of British Columbia, was one of the recent award winners; with her grant, she opted to spend 1987 at Johns Hopkins University. Greenwood, whose specialty is the study of random processes (a branch of probability and statistics) gave lectures and collaborated on research with Hopkins faculty.

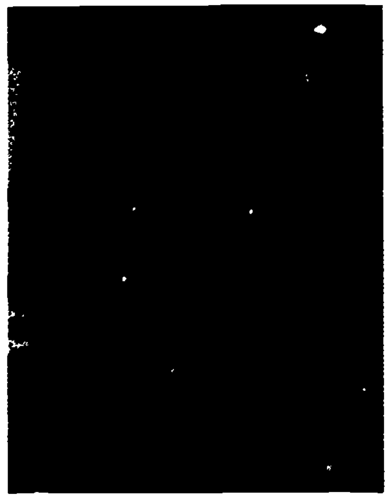
**Florida State meets Harvard.** A special NSF grant for women scientists enabled Jill S. Quadagno, a sociology professor at Florida State University, to spend six months at Harvard University.

**Minority Research Initiation.** A graduate student in the solid-sta... electronics laboratory at Howard University holds a high-speed optical shutter made from silicon carbide.



**Research opportunities.** Student researchers conduct experiments in the laser spectroscopy laboratory at Howard University. They are funded under NSF's Minority Research Initiation program.

**...rch Improvement in Minority Institutions.** At the University of ...o Rico-Rio Piedras, NSF-supported mathematics staff and ...chers work on the Alliant computer.



**Visiting scientist.** Juana V. Acrivos, a professor of chemistry at San Jose State University, was awarded an NSF Visiting Professorships for Women grant to spend a year in the chemical biodynamics laboratory at the University of California, Berkeley. Her disciplinary area is solid-state chemistry.

**Astronomical visit.** Alice L. Newman, a member of the technical staff of the Aerospace Corporation in Los Angeles, has broadened her research experience during a one-year stay at Cornell University's Department of Astronomy. The visit was made possible by an NSF Visiting Professorships for Women grant.

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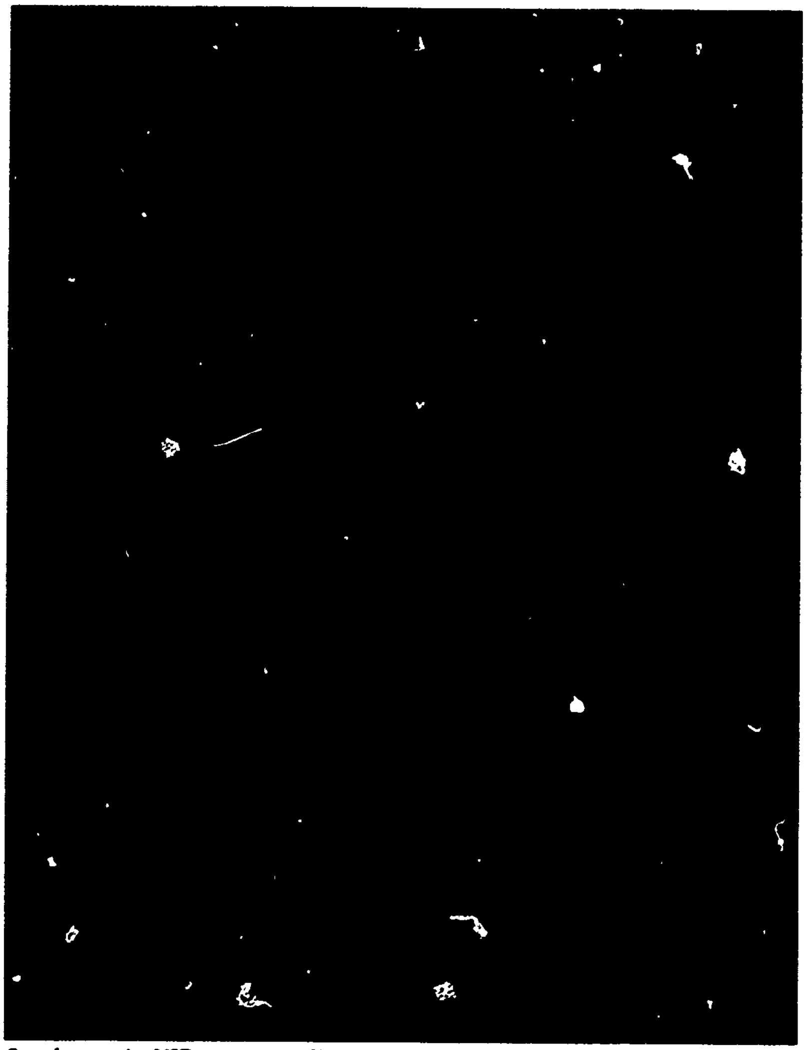


**Sea change. An NSF grant gave Ellen R. Druffel, a marine chemist at the Woods Hole Oceanographic Institution in Massachusetts, the opportunity to spend a year at the University of California at Santa Cruz.**

- In 1987 NSF announced the first two grants under its Minority Research Centers of Excellence (MRCE) program, a new initiative to address the continuing shortage of minority scientists and engineers in fundamental research. In addition to supporting qualified scientists, the MRCE's also seek to attract talented minority students to careers in science and engineering through scholarships and new research opportunities.

Researchers at Howard University's MRCE in Washington, D.C. will investigate materials important in telecommunications, defense, and industrial applications. At Meharry Medical College, the MRCE will establish a cellular and molecular biology research center focusing on three areas: studies of DNA reproduction critical to viral infection and mutations, enzyme studies that may provide a better understanding of fat metabolism, and upgrading of a neurobiology laboratory. The Meharry center will provide scholarships and research programs for high school students as well as undergraduates.


Hugh Moore & Associates

In an effort to boost research at schools that offer few advanced degrees, NSF funds several activities. For example, the Predominantly Undergraduate Institutions Program supports research at institutions that awarded no more than 20 science and engineering doctorates in fields supported by NSF during the past two years. The Research in Undergraduate Institutions initiative funds scientists at these institutions who work in departments that do not offer the doctoral degree. And Research Opportunity Awards enable science and engineering faculty to collaborate with NSF-funded investigators at better-equipped research universities.

Finally, there is an experimental program called University/Industry/Government Partnerships for Quality Engineering Personnel. The emphasis here is on incorporating major elements of engineering practice into engineering curricula, enabling students to be taught by adjunct faculty with a practical engineering orientation. In many cases, the partnership provides university students with industrial or other facilities and equipment used by the practicing engineer.

## OUTREACH TO THE PUBLIC

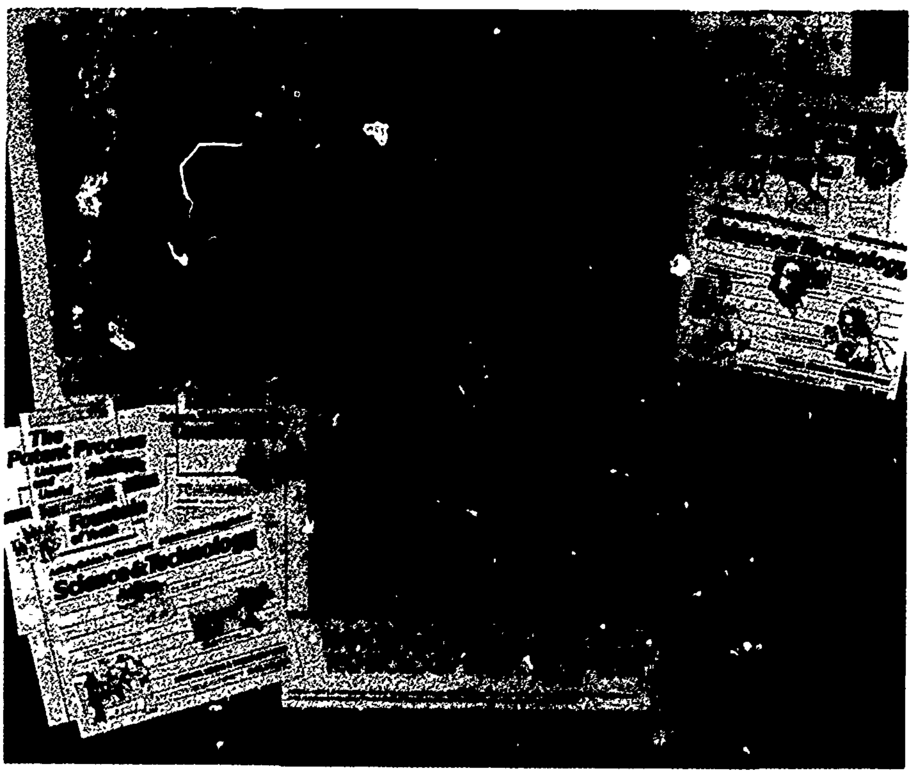
### National Science and Technology Week

In parallel with NSF's array of awards and fellowships to upgrade science education and research in schools and universities, the Foundation also supports activities that boost the public's awareness of science. Among these activities is National Science and Technology Week (NSTW).

The goals of NSTW are twofold: to raise public awareness of science, engineering, and mathematics, and to encourage young people to seek careers in these areas. A major component of NSTW 1987, held April 5-11, was the distribution of 130,000 education packets, one to every elementary and middle/junior high school in the country. The packets contained suggested teaching activities with hands-on experiments for students, science and mathematics teachers were trained to use the packets effectively at pilot workshops across the country.

Pam Shapiro

**"Today" applauds tomorrow's scientists. NBC "Today" weather reporter Willard Scott congratulates winners of the New York science fair at the AT&T Infoquest Center in New York City. The contest was one of many events linked to National Science and Technology Week 1987.**



Patrick Olmert

**Spreading the word. Some 130,000 teaching kits—as well as posters and "how to participate" brochures—helped bring attention to National Science and Technology Week 1987.**

Other NSTW activities: The New York Academy of Sciences coordinated a national "Art of Science" competition for high school seniors (see "Highlights"). In Texas, a science and technology festival highlighted the contributions of local research corporations and universities. And nationwide, children in more than 600 schools kicked off the week by releasing 250,000 balloons with attached weather cards. Data from the nationwide experiment indicated wind and weather patterns and were sent in a postlaunch packet to participating schools.

In addition, the beauty and variety of life on earth and the complex issues surrounding its survival were the focus of a travelling exhibit first made available during NSTW. The exhibit, entitled "Diversity Endangered," was produced by the Smithsonian Traveling Exhibition Service, with support from NSF.

**National Science & Technology Week activities will increase awareness of the vital role science and science education play in improving our economic competitiveness, and our quality of life. Today science is not a part of the basic curriculum in many U.S. elementary schools. We're working to correct this.**
— Erich Bloch, Director
National Science Foundation

## States Initiative

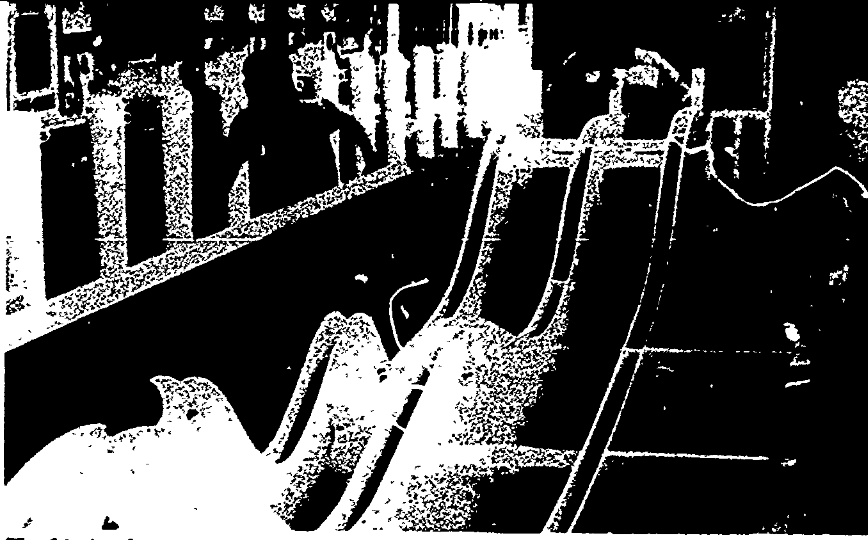
In view of the increasing importance of cooperation and cost sharing — and recognizing the growing role of the states in supporting science/engineering research and education — the Foundation is working to strengthen communication with state governments. A recent effort — initiated by NSF's Office of Legislative and Public Affairs — began with a pilot project in four states: Arkansas, Michigan, New Jersey, and Utah. These states were chosen for their geographic representation, their diverse economies, the range of research and educational resources available to their leadership, and their strong commitment to pursuing excellence in research and education

This project enabled NSF to establish contact with key people and organizations in each of these states, discuss mutual concerns, exchange information and ideas, and focus attention on national needs in research and education for science and engineering. The project also offered a first-hand look at how the states are working with universities and industry to link research and education with their plans for economic development. The effort is expanding to other states, and close ties have developed between NSF and the National Governors' Association.

## Museum Programs

It was in 1970 that NSF made the first grant for a different kind of museum, one where people would learn by exploring, touching, experiencing, and trying to explain. Today, after years of NSF support, centers such as the San Francisco Exploratorium have become the standard for science museums throughout the world. NSF-funded museums have even entered the formal teaching business — for example, the Lawrence Hall of Science in Berkeley, California developed materials for Boy Scout and Girl Scout leaders to teach outdoor biology.

NSF provides seed money for a variety of new science museum programs. At the St. Louis Science Center, NSF funds have helped develop a science playground to teach children about motion, energy, light, sound, and the natural environment. The physics of motion can be explored through such devices as a friction slide, gravity hoop, and the familiar roller coaster ride. Children learn about energy by exploring watermills and the subject of water power; playing with kaleidoscopes teaches them about the nature of light.

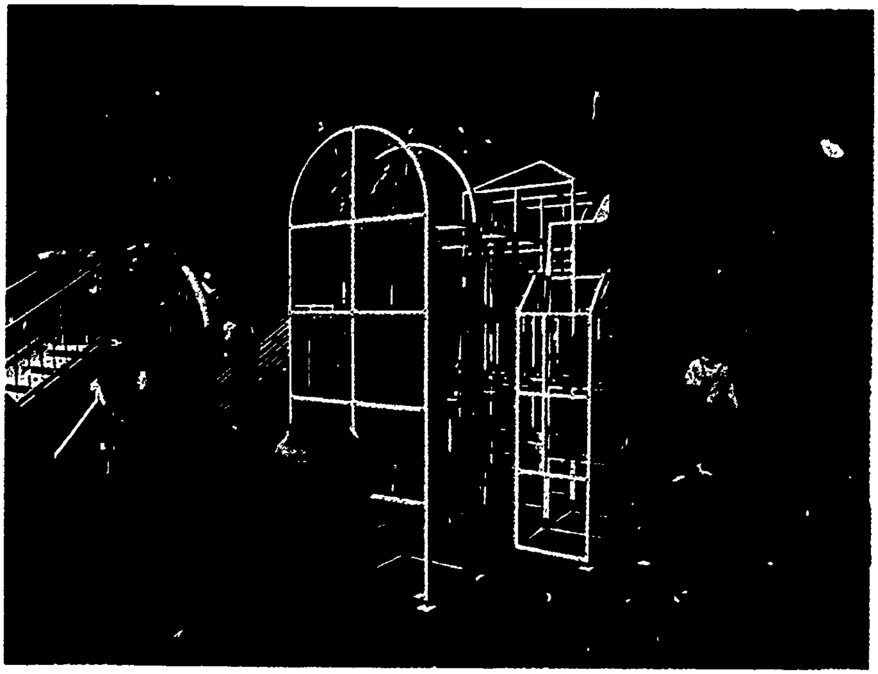


St Louis Science Center

The friction factor. In this exhibit, two balls race down a circular track; one is partially filled with sand and the other is solid. Because of internal friction, the sand-filled ball soon stops accelerating and the solid ball always wins the race.

Erwin Gebhard, courtesy of *Milwaukee Journal*

Setting up exhibit materials at the Milwaukee Public Museum

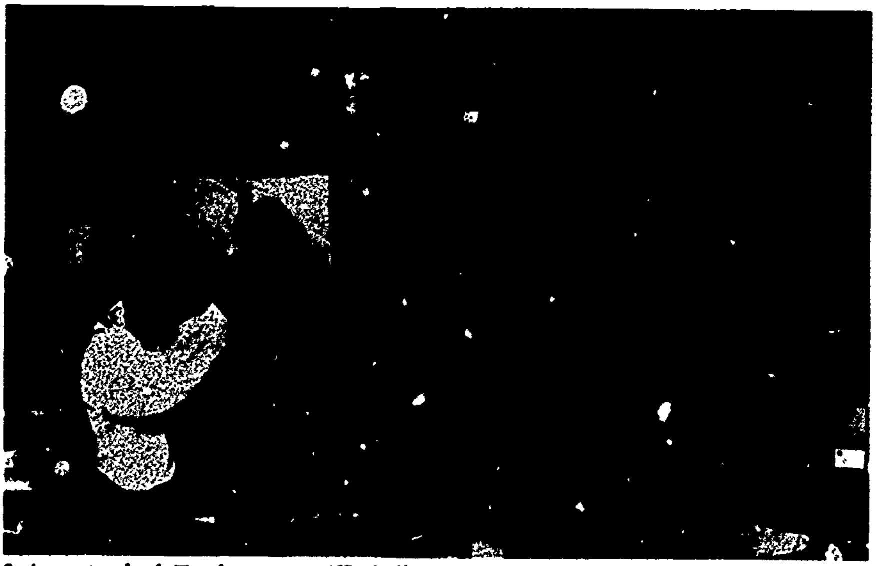


St. Louis Science Center

Gears and gizmos. At the St. Louis Science Center, visitors learn how gears drive six different assemblies, including a clock, giant puppet, and laser-etched disk.

Richard Hoyt

A touching experience. Children pet a reptile at "Animals in Action," an activity at the Lawrence Hall of Science, University of California at Berkeley.



Strings attached. Teachers use wiffle balls and string to demonstrate the gravitational force between the earth and moon. They are participating in the Franklin Institute's Teacher Overnight Science Program in Philadelphia, PA.

In addition to providing monetary support, NSF helped establish the first association of these science centers (the Association of Science-Technology Centers), so that informal educators could share their ideas and learn from one another. As a result, science museums today routinely collaborate on projects and ensure that travelling exhibits reach millions across the United States

## Television

NSF also provides key support for several television science series During 1987, NSF gave the award-winning science program *NOVA* a special grant for an hour-long show on Supernova 1987A, the most important stellar explosion of its kind since the time of Galileo (see "Highlights" section).

NSF also supported the filming of "Stand and Deliver," a Public Broadcasting System (PBS) drama that chronicles the real-life success of Jaime Escalante and his nationally acclaimed mathematics program at Garfield High School in Los Angeles. Overcoming crime, poverty, and a 50 percent dropout rate, Mr Escalante transformed his Hispanic students into some of the top calculus students in the country and helped turn Garfield High into a magnet school for science and math The program stars Edward James Olmos, Emmy award-winning star of the *Miami Vice* television show "Stand and Deliver" is being aired in both English and Spanish as part of PBS's *American Playhouse* series. (It was also released by Warner Brothers as a feature film in the spring of 1988.)

Mitzi Trumbo. © Warner Brothers Inc. 1988

**Math teacher recognized. NSF supported the filming of "Stand and Deliver," a drama that chronicles the real-life success of teacher Jaime Escalante (right), from Los Angeles' Garfield High School. Escalante, played by *Miami Vice* actor Edward James Olmos (left), helped his students become some of the top calculus students in the country, turning Garfield into a magnet school for science and mathematics.**

Tony Friedkin © Warner Brothers Inc 1988

**Edward James Olmos, portraying mathematics teacher Jaime Escalante, holds an award as he is surrounded by students.**

Children's Television Workshop

Dynamic duet. Mathwoman (Beverly Mickins) and Robert (Luisa Leschin) are two of the many characters who deliver messages about mathematics to children on *Square One TV.* The daily series for 8 to 12-year-olds began in 1987.

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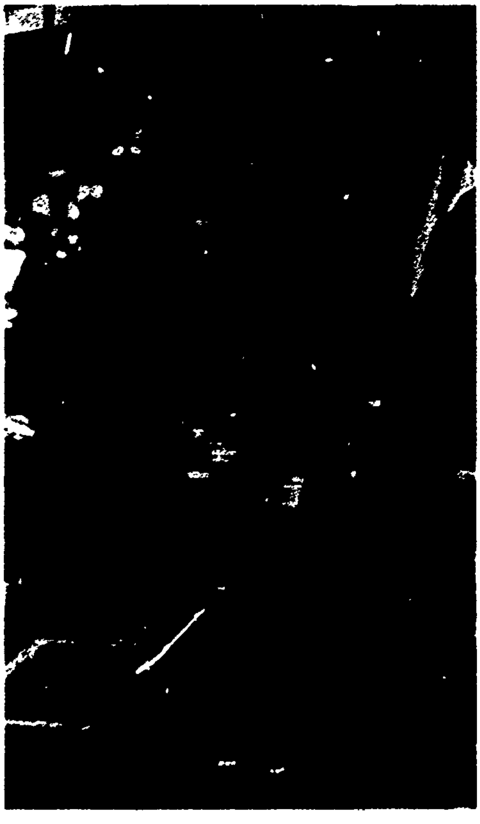
NSF continues to fund *Reading Rainbow*, the PBS series that introduces children to books through book reviews that combine reading aloud and displaying illustrations from the text. NSF support helped to produce five programs devoted to science books and science topics. NSF also funds one of PBS's latest educational efforts, *Square One TV*, designed to promote a greater enthusiasm for mathematics among the nation's third to sixth graders. This group may be crucial to reach: studies indicate that while most children enjoy arithmetic through grade three, their interest wanes starting in the fourth grade as they are exposed to long division, compound fractions, and other more complicated functions. By middle school, students may already be turned off on mathematics.

During a typical *Square One* episode, a rock group weaves square numbers into the lyrics of a zany song; a parody of a soft drink commercial delivers a lesson about subtraction; and the sign maker at Harry's Hamburger Haven teaches the viewer about decimals. Each half-hour show ends with an episode of "Mathnet," in which lead characters use math and problem-solving techniques to solve mysteries such as "The Problem of the Trojan Hamburger." Preliminary comments from more than 3500 children around the country helped shape the format and content of this program.

NSF also helped fund *The Ring of Truth*, a six-part series that gave a personal view of science through the eyes of noted physicist and science writer Phillip Morrison and his wife Phyllis Morrison, a distinguished science educator. The series first aired on PBS during the fall of 1987.

***3-2-1 Contact.*** **Co-host Debra Shapiro visits New York's Cathedral of St. John the Divine to learn how a building arch is designed and constructed. This television show is supported in part by NSF and is aimed at 8 to 12-year-olds.**

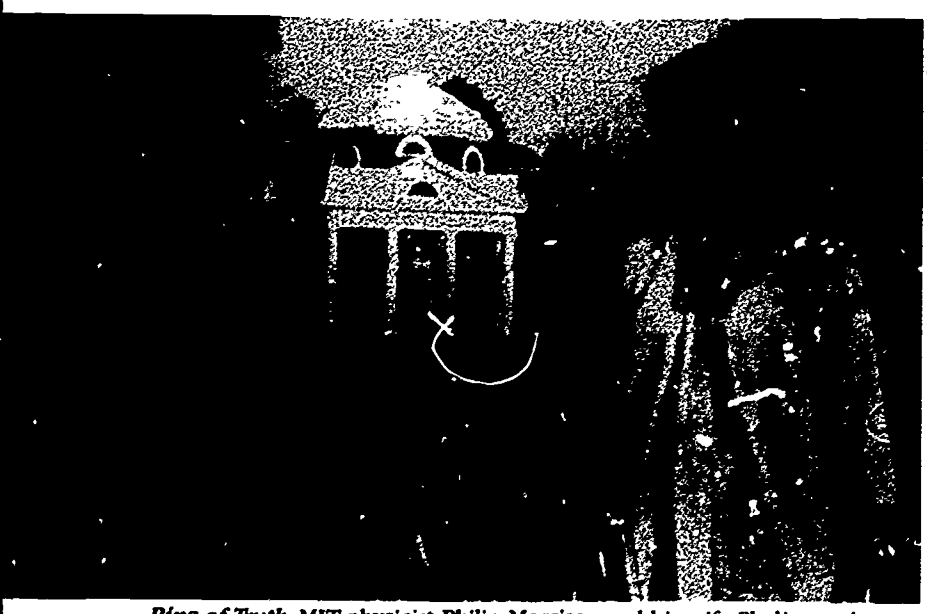


***Contact*** **visit. David Quinn and Kaori Tomita, from television's *3-2-1 Contact*, visit the Skiji Fish Market in Tokyo to learn about the different kinds of fish that make up a typical Japanese diet.**

## Special Outreach Programs

In 1978, Joan Humphries, an Equal Opportunity Manager at NSF, and Oceola Hall of NASA established an interagency committee for women scientists and engineers, known as WISE. The purposes of WISE are to encourage women scientists and engineers to seek careers and advance in the Federal Government; to encourage young girls studying science and math to pursue scientific or engineering careers; and to ensure that excellence in female scientists and engineers is recognized.

**Joan Humphries**



Vittoriano Rastelli

***Ring of Truth.*** **MIT physicist Philip Morrison and his wife Phylis, a science educator, host this series on science. They are shown here at Thomas Jefferson's Monticello, during a segment on mapping.**

As part of its annual national training conference, WISE sponsors a day-long program for talented 9th- and 10th-grade girls in the Washington, D.C. area. The group also presents three national awards recognizing the outstanding accomplishments of federally employed women scientists and engineers.

NSF staff members also participate in the Washington, D.C. chapter of Minority Women in Science (MWIS). The local chapter, part of a national network established in the 1970's, provides a communication and support system for minority women who are researchers, educators, or administrators in the fields of science and engineering. Since 1980, the D.C. chapter has sponsored "Science Discovery Day," in which junior high school students, their teachers, and parents meet and talk with MWIS members.

Other MWIS activities include:

- A workshop for precollege teachers, held annually since 1981;
- A speakers' bureau for local educational events and programs;
- A science fair and provisions for monetary awards and certificates for outstanding science projects.

Finally, there is outreach to university faculties. Foundation staff members make a special effort to reach out to their clientele by making presentations about NSF and its programs, and by conducting proposal development workshops. These may be visits to single institutions, often in conjunction with other official travel, or more formal colloquia/workshops, sponsored by a college or university acting as host for regional institutions. In 1987 formal regional colloquia were presented at institutions in 22 states, followed by informal one-to-one sessions as time permitted.

# CHAPTER 3

# DISCIPLINARY RESEARCH

While emphasis and attention in disciplinary research may shift from one area to another, the unpredictable nature of scientific investigation requires that support be maintained in all disciplines. Whether it be research conducted at the chalkboard by a small group of scientists or at a proton accelerator shared by large teams of investigators, NSF-supported efforts continue to respond to the challenge of searching for new knowledge. Hand-in-hand with the Foundation's commitment to research is increased emphasis on interdisciplinary studies and on new forms of collaborations between government, universities, and industry. These themes are evident in NSF-funded research during 1987, as described in this chapter

## PHYSICAL SCIENCES/ MATHEMATICS

### Astronomy: Arcs and Black Holes

While the discovery of the most brilliant stellar explosion since the time of Galileo dominated the year in astronomy (see "Highlights"), the results of other NSF-supported research efforts also made headlines. For example, scientists using a telescope at Kitt Peak National Observatory in Arizona reported the sighting of giant blue arcs, trillions of miles long, that encircle at least two distant galaxies.

The arcs, some of which are three times as large as our own galaxy, the Milky Way, are the longest continuous features ever detected by telescope. Glimpses of the arcs were first sighted a decade ago, but their extraordinarily uniform structure was observed only recently with the help of the 157-inch (4-meter) reflector telescope at Kitt Peak and special electronic sensors. At first scientists thought that the arcs consisted of newly formed stars arranged along a curved shock front. However, at this writing they think that the arcs are images formed by a gravitational lens. In one case, the actual object is thought to be about twice as far away as the galaxies seen near the arc. The lens is probably a cluster of galaxies between us and the object.

In other research, an astronomer has found evidence that the Milky Way galaxy is part of a flat, oblong "supercluster complex" that encompasses millions of galaxies and stretches one-tenth the distance across the observable universe.

The supercluster complex is about 1 billion light years long and 150 million years across, according to its discoverer, *Brent Tully*, at the University of Hawaii's Institute for Astronomy in Honolulu. Tully has named the structure the Pisces-Cetus Supercluster Complex, after the constellations in whose direction it is found.

The evidence for the supercluster complex, 100 times more massive than any previously known structure, would suggest that, on this immense scale, galaxies are not randomly distributed throughout the cosmos, but are instead clustered in space in a way that is not anticipated by current conventional theories of galaxy formation.

Black hole. In this supercomputer simulation, the round image represents a calculation of the accretion of rotating gas onto a black hole in space. (This supercomputer work was done at the National Center for Supercomputing Applications at Champaign, IL.)

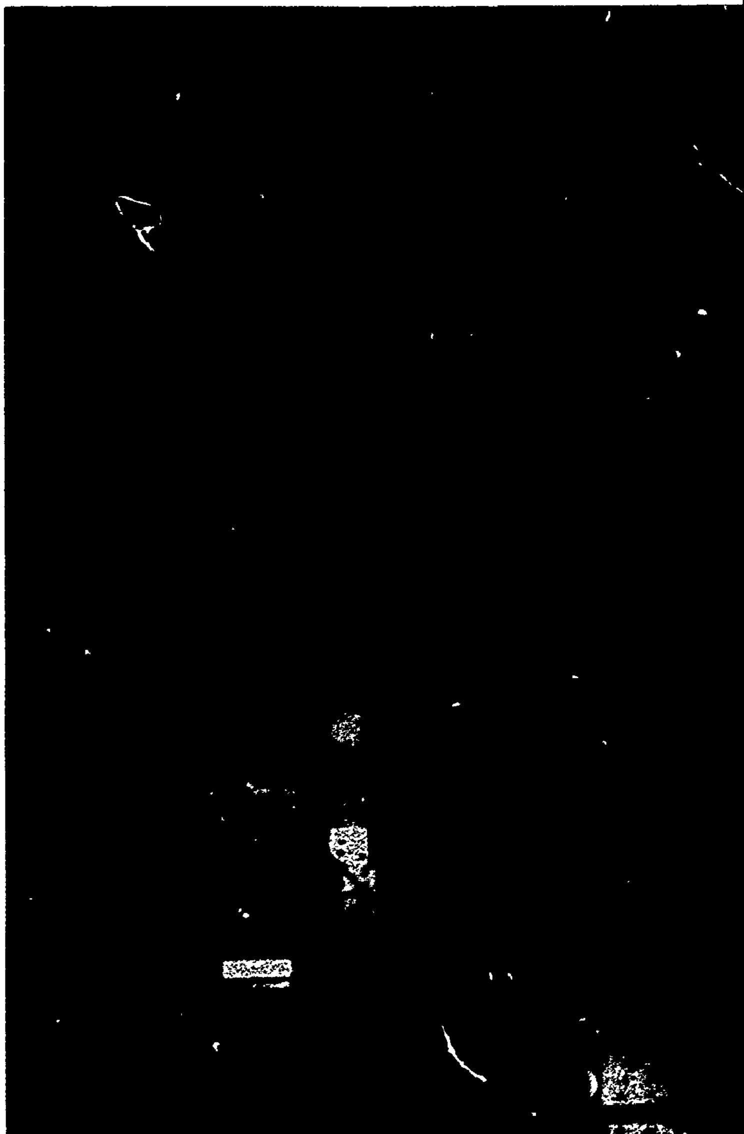
Finally, astronomers found evidence in 1987 that massive black holes — objects whose gravitational force is so strong that not even light can escape their pull — are at the hearts of the two galaxies closest to the Milky Way. (These galaxies are Andromeda, called M31, and its companion, called M32.) The new, indirect evidence suggests that black holes may be at the centers of other galaxies, including our own, and supports the theory that black holes are the power source in the centers of galaxies and brilliant quasars. This research was done at the University of Michigan and at Mt. Wilson and Las Campanas Observatories in Pasadena, California. The astronomers involved were *Douglas Richstone* and *Alan Dressler*.

### Chemistry: Research on Molecular Electronics

A chemist at the Massachusetts Institute of Technology has discovered molecular substances that mimic properties of electronic circuits. Like wires mounted on a computer chip, sections of these substances fashioned into wire-like strands no more than 500 atoms wide emit tiny electrical signals in response to stimuli. But unlike the typical electronic circuit, the molecular electronic circuits produce voltage changes only in response to the presence of nearby chemicals, such as carbon monoxide. *Mark Wrighton* and his research team have found 10 such "chemical circuits," each responding to a different chemical stimulus. Mounted on plastic and as easily transported as a computer chip, these circuits may have wide application as highly accurate chemical sensors.

In other research, a relatively new microscopic technique has given chemists the first close-up glimpse of the surfaces of compounds while they are submerged in a liquid or a gas. Previous research using an electron microscope (a device that uses electron beams, rather than light, to "see" tiny structures) required that the compound under study be placed under high vacuum and isolated from the chemicals with which it could interact.

Because the newer tool maps surfaces of chemicals in their natural state, chemists — including *Allen Bard* of the University of Texas at Austin — have been able to make nearly atom-by-atom pictures of the interface between liquids and metals. They also have observed surface changes in



**STM. Lev Ovadia, a visiting scientist at the University of Texas at Austin, is shown with the scanning tunneling microscope or STM.**

biological membranes during chemical reactions The revolutionary image device, known as the scanning tunneling microscope (STM), is opening new doors in understanding the chemistry of surfaces and chemical reactivity on an atomic scale.

STM's map the microscopic hills and valleys of surfaces much the way a phonograph stylus senses the grooves of a record. But the ultrafine tip of the STM never touches the surface it maps. Instead, the needle-like tip is kept about 10 atomic diameters away, allowing a tiny current of electrons to tunnel through the gap between the tip and the surface The rate of electron absorption by the compound's surface gives a detailed map of its structure. At this writing, Allen Bard has used the tunneling microscope to measure the topology of platinum, iron compounds, and nickel.

### Statistics: Some Modern Applications

Statistics are increasingly invoked in critical decision making. For example, discrimination suits typically depend on statistical arguments showing bias toward a particular subgroup to which a defendant belongs, since discrimination is hard to "prove" on a case-by-case basis. Statistical methods are essential in more complicated legal cases, where only limited information is available, in deciding the guilt or innocence of an individual. Similar methods can be used in many other situations, such as assessing environmental risks.

To help answer such thorny questions, Carnegie Mellon University's *Morris De Groot* pursues a branch of study called Bayesian Analysis. First developed during the last century, this procedure has become widely popular over the last 20 years. Bayesian Analysis gives mathematical structure to prior information (e.g., personal judgments and the validity of each piece of data) and greatly enhances decision making. The field of image processing has been greatly improved using these methods. According to De Groot, Bayesian Analysis has the potential to aid in weather forecasting, economic predictions, and risk assessment.

Statistical techniques are also at work in research on the cellular material DNA (deoxyribonucleic acid). DNA from seemingly unrelated organisms has been found to possess large regions that are closely related. These similarities may hold valuable information. For example, an unexpected similarity between human DNA and DNA associated with viruses has suggested a possible genetic mechanism for the cause of cancer. However, many small fragments of the long DNA strands resemble one another only by chance. It is the task of modern probability and statistics to screen out these chance matchings and recognize true patterns that allow scientists to focus on regions of DNA likely to have biological importance. *Samuel Karlin* at Stanford University and *Michael Waterman* at the University of Southern California are among the NSF-supported scientists who work in this field.

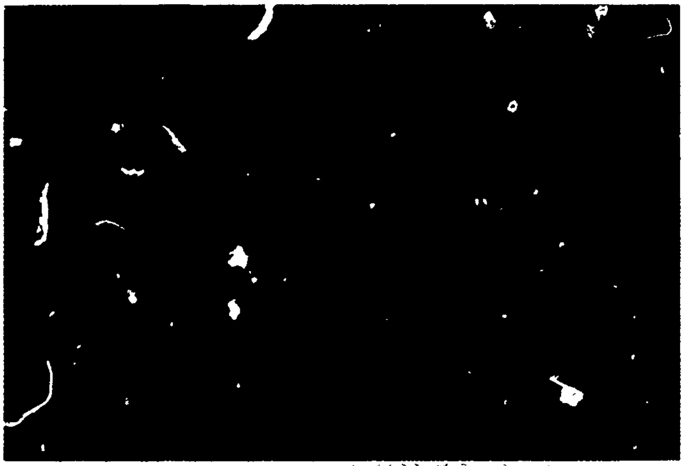
## BIOLOGICAL SCIENCES

### Wounded Plants Practice Self-Defense

Scientists are studying the mechanisms that cause wounded plants to produce chemicals that protect the plants from further damage. Researchers have found that certain plants, when attacked by insects, produce chemicals that inhibit the insects' digestive enzymes, discouraging them from eating more of the plants. The same protective chemical effect occurs in the laboratory if a tool is used to simulate an insect bite. In the tomato, potato, and alfalfa plants under study by *Clarence Ryan* and his colleagues at Washington State University in Pullman, the protective chemicals were produced both at the wound site and in leaves, stems, and areas far from the wound. The Washington State researchers found that the chemicals persisted for weeks, and sometimes months, in cells throughout the plants.

According to Ryan, the plants' protective reaction is similar to that of an immune system. In response to an attack, such as an insect bite, the plant is stimulated to prevent further damage. But rather than producing antibodies, as in an animal immune system, the wounded plants produce chemical mediators from the breakdown of cell walls damaged at the wound site. These mediators may be the first step in creating chemical signals that circulate throughout the plant and stimulate production of the protective chemicals. Researchers around the world have found evidence that chemicals created by cell wall fragments in plants play a role in protective responses.

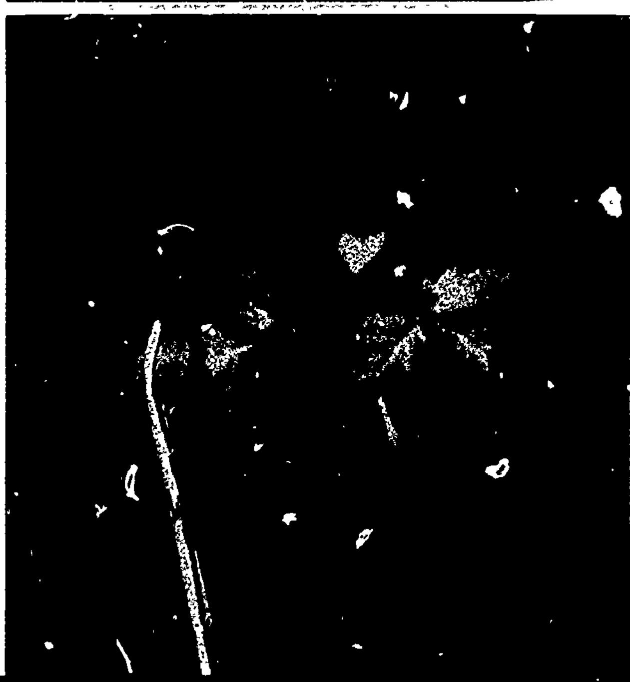
Ryan and his colleagues have identified and cloned from potato plants two genes that code for proteins which interfere with insects' ability to digest plant material. Through genetic manipulations, researchers such as Ryan hope to induce protective chemical responses in many agricultural crops, making them more resistant to insect and other damage.



Self-protection in plants. When wounded by insects, some plants protect themselves from further damage by triggering a series of chemical events, as shown in this hypothetical model.

Clarence Ryan

Protective mechanism. A Colorado potato bettle triggers the tomato plant it is feeding upon to release proteins that inhibit the insect's digestive enzymes. As a result, insects are discouraged from eating more of the plant.



C Ryan

Laboratory predator. Crushing leaves with a hemostat in the lab simulates the damage caused by insect attacks.

## Genetics of the Mustard Plant

A distant cousin to the common mustard plant, *Arabidopsis thaliana* is creating excitement in the community of scientists who want to understand how genes are regulated in plants and how, in turn, the genes regulate the life processes necessary to the plant. It has been difficult to study the molecular genetics of most plants because of the large amount of genetic material, the large number of DNA sequences which are repeated many times, and the long period of time needed to grow plants. *Arabidopsis* is changing that. First studied at the molecular level by *Elliot Meyerowitz* and his associates at the California Institute of Technology, *Arabidopsis* has been shown to have the smallest amount of genetic material of any plant known. (For example, the genome size for wheat is 5,900,000 kilobases, compared to 70,000 kilobases for *Arabidopsis*.) Furthermore it has very few repeated DNA sequences, and, best of all, takes only five weeks to grow from a seed to an adult plant. All of these facts, plus 40 years of genetic information gathered in the past, make it possible for scientists to ask very specific questions and, they hope, get very specific answers.

Meyerowitz is continuing the molecular characterization of this plant by making a complete restriction map of the genome. The genome is the genetic material, and a map can be made by the use of enzymes (restriction enzymes) that cut only in very specific areas of the DNA. If enough different restriction enzymes are used, one has specific sign posts which can serve as markers to localize a gene within the genome Such localizing is often a first step to cloning a gene, and cloning is often a first step to identifying both what it does and how it does it.

As a larger project, Meyerowitz and his associates are also studying flower development in this plant His associate on the initial molecular characterization was a graduate student, *Robert Pruitt* After obtaining his degree, Pruitt became an NSF Plant Postdoctoral Fellow. At this writing, he is at the University of Minnesota and plans to study male sterility in *Arabidopsis*.

Other scientists have begun to identify and clone genes in *Arabidopsis*. *Joseph Ecker* at the University of Pennsylvania (also previously an NSF Plant Postdoctoral Fellow) is interested in how plant hormones are synthesized and is using this weed to find out. *C. Sommerville* of Michigan State has cloned a gene and shown that a one base change in the gene causes *Arabidopsis* to become herbicide resistant. *David Meinke* of the University of Oklahoma has created a mutant that can no longer make biotin, a vitamin; he will undoubtedly clone the mutated gene in the near future.

One of the most exciting and potentially productive pieces of work being done with this organism is that of *Gerald Fink* at M.I.T.'s Whitehead Institute. An NSF Plant Postdoctoral Fellow in his laboratory, *Robert Last*, has succeeded in creating an *Arabidopsis* plant—an auxotrophic or nutrient-requiring mutant—that will not grow unless a specific amino acid, tryptophan, is added to the medium in which it is growing. This is exciting because it has been extremely difficult to produce auxotrophic plants. The reasons for this are not known, but many scientists have tried to surmount the difficulties because of the immense body of knowledge accumulated by studying bacterial auxotrophs.

Moreover, in this experiment, the specific amino acid required, tryptophan, is thought to be a precursor for auxin, a plant hormone essential for normal plant growth. The mutant plant shows all the expected characteristics of a plant that lacks auxin, and it can be essentially rescued by the addition of tryptophan to the medium.

An interesting by-product of this mutation is the accumulation of a compound which cannot be converted into tryptophan because of the mutation and which causes the whole plant to fluoresce in ultra-violet light.

In a parallel study in the same laboratory, *Mary Berlyn*, an NSF Visiting Professor, has cloned the gene-encoding tryptophan synthesis, perhaps the same gene mutated in the fluorescing plant. The way is open for studying a biosynthetic amino acid pathway in plants; understanding how the gene encoding the mutated enzyme is regulated and how hormones act in plants, and perhaps gaining insight into the isolation of other kinds of nutritionally deficient plant mutants.

*Arabidopsis* is a weed No matter what we learn or how we engineer it, we will probably never use *Arabidopsis* as a crop plant or eat it. However, what we do learn about the basic genetics and biology of this weed will have a great impact on the potential for bioengineering food plants.

Robert Paz, Caltech

**Genetics team. At the California Institute of Technology, Elliot Meyerowitz (far right) and his research team study plant genetics.**

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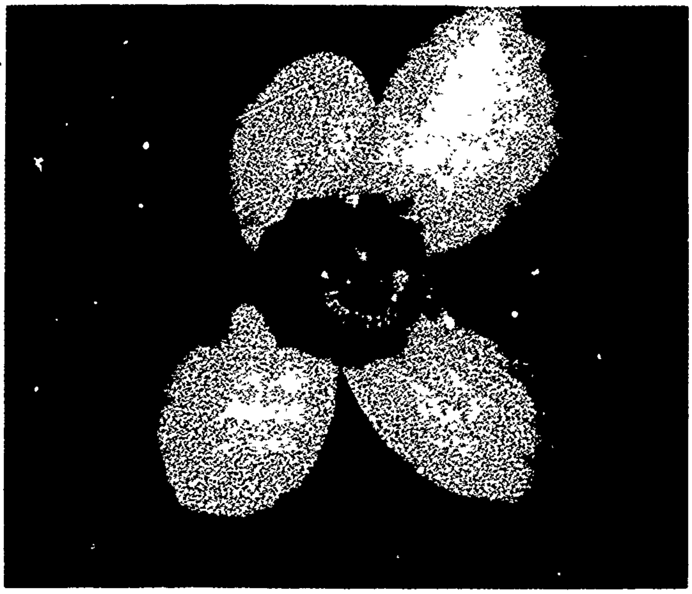
Elliot Meyerowitz



Plant watch. Researchers examine the *Arabidopsis* flower to understand genetic behavior. First photo shows normal growth; the four white petals, six anthers, and central stigma are visible. Second photo is a mutant flower of *Arabidopsis*. Genetic manipulations in the laboratory caused the flowers of this plant to consist of many whorls of petals and sepals, without the usual stamens or ovary.

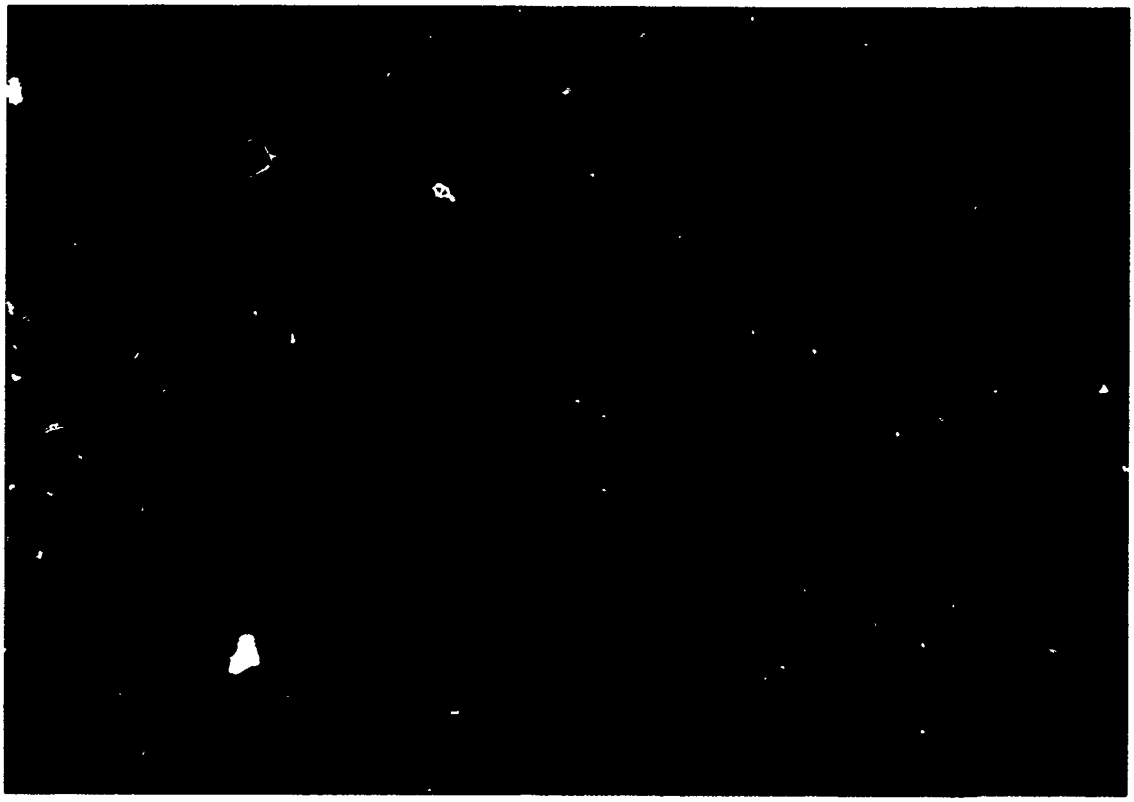
## Communication Between Cells

For years, scientists have studied the flashes of light emitted by a variety of biological species. Some marine organisms may emit light to ward off fish; other animals may use light to attract a mate or in response to chemical stimulation. But the details of how bioluminescence is triggered have remained a mystery.

Researchers *Kathleen Dunlap* and *Paul Brehm* at the Tufts University School of Medicine in Massachusetts have found new clues to understanding bioluminescence in studying a simple marine organism only two cell layers thick — the coelenterate. Certain cells of this organism emit short bursts of green light in response to increases in calcium intake.

Using a video camera connected to a microscope to record the exact location of the tiny light bursts, the scientists found that the first regions of the cells to light up were those in direct contact with nonluminescent cells that produce a small electrical signal when stimulated. When direct contact between the nonluminescent cells and the light-emitting cells was blocked, no light was emitted. According to the researchers, their work is supporting evidence that the connecting structure between the two types of

Mutation in plants. *Arabidopsis thaliana*, which are mutant for tryptophan biosynthesis, fluoresce under ultraviolet light because of the accumulation of an intermediate compound. The nonmutant plant in the background (large dark blue objects) does not fluoresce. The mutant plants (small, light blue objects) were isolated by Robert Last, an NSF Plant Postdoctoral Fellow working in the laboratory of Gerald Fink, at MIT's Whitehead Institute.



cells, known as a gap junction, plays a crucial role in triggering the flashes of light.

Because no electrical voltage change has been detected in the light-emitting cells, scientists believe that it is a chemical signal rather than an electrical one that flows through the gap junction to trigger the light flashes

This research, which provides the first evidence that a chemical passes through gap junctions to stimulate bioluminescence, highlights the importance of chemical signals in communication between cells.

**Luminescent animals. The coelenterate *Obelia* is the organism in which Kathleen Dunlap and Paul Brehm have been studying the control of bioluminescence.**

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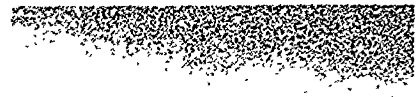


Elizabeth Tai

## GEOSCIENCES

### Polar Programs

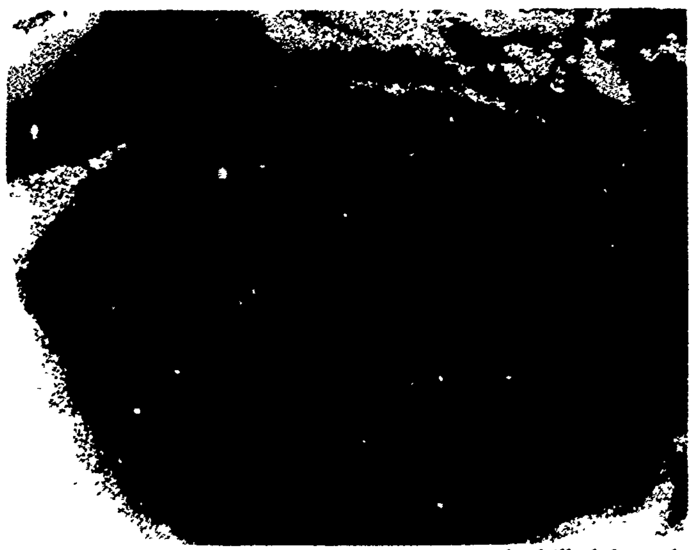
NSF-supported basic research in the antarctic and arctic regions explores polar ecology and biology, meteorological processes, climate history, glacial dynamics, regional geology and its global significance, the influence of polar oceans in global weather and climate, and sun-earth interactions. NSF funds and manages the United States Antarctic Program, which stresses science as the principal expression of U.S. interest in Antarctica, under an international treaty. The Foundation is also the lead U.S. agency on the Interagency Arctic Research Policy Committee, discussed later in this section.

A 1985 report by British scientists that the stratospheric ozone over Antarctica is depleted by as much as 50 percent during the austral spring has generated intense research interest, including two National Ozone Expeditions to McMurdo Station on the antarctic coast (see "Highlights").

In another NSF-backed antarctic project, atmospheric physicists have been investigating the earth's magnetosphere. From a special transmitter at Siple Station, they send very-low-frequency electromagnetic waves into the earth's upper atmosphere. These waves follow the geomagnetic field lines that thread the magnetosphere and intercept the earth's surface and ionosphere in polar regions. By analyzing the changes in the waves, detected in the northern hemisphere at Lake Mistissini, Canada, scientists have learned much about the composition of the magnetosphere, as well as the way electromagnetic disturbances may affect communications.

In 1987 geologists and paleontologists from four U.S. universities discovered the fossil remains of a 6-foot-tall, flightless bird, the jaw of a large crocodile, and 50 fossil lobsters.

Shadow on ice. An Emperor penguin casts a shadow on the ice edge of the Ross Sea in Antarctica.



Elizabeth Tait

Expected company. A seal pops up in a hole drilled through 12-foot-thick ice covering McMurdo Sound near Antarctica.

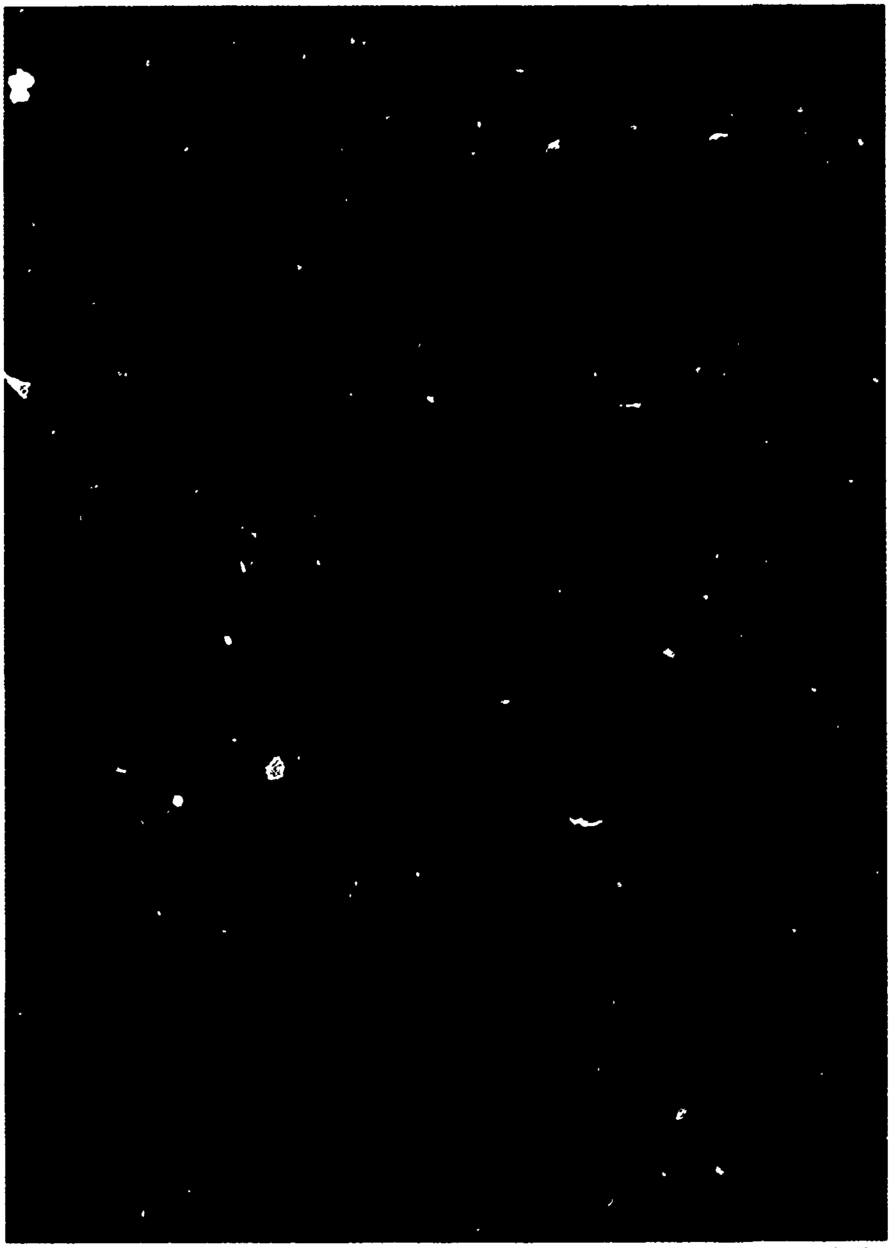
UNITED STATES OF AMERICA
ANTARCTIC PROGRAM

The discoveries, made at Seymour Island (a rugged, barren area near the top of the Antarctic Peninsula), support theories that a land bridge connected Antarctica and South America between 40 and 140 million years ago and that contemporary marine organisms, now living in temperate waters, originated in the high latitudes.

Overall, field work in Antarctica consisted of 74 research projects at numerous summer-season camps, three year-round stations, and work on board research ships.

In arctic research, a team of scientists travelled to Greenland in July 1987 to make some of the most sensitive geophysical measurements ever done of the Newtonian gravitational constant and to test a new hypothesis that a fifth, yet undiscovered, force may exist in the universe. The experiment was designed to verify earlier measurements that indicate a variation of the gravitational constant with distance. Laboratory measurements of gravity are generally limited to lengths of a few inches.

The scientists used a gravity meter, which was lowered into an existing 6700-foot hole bored into the Greenland ice sheet to measure the gravitational constant, commonly called the "big G" by physicists. After lowering the meter to 5000 feet, the researchers measured, in 300-foot intervals, changes in the force of gravity at different depths. The discovery of gravitational variations would have a significant impact on several branches of modern physics and would require the recalculation of the masses of planets and stars.

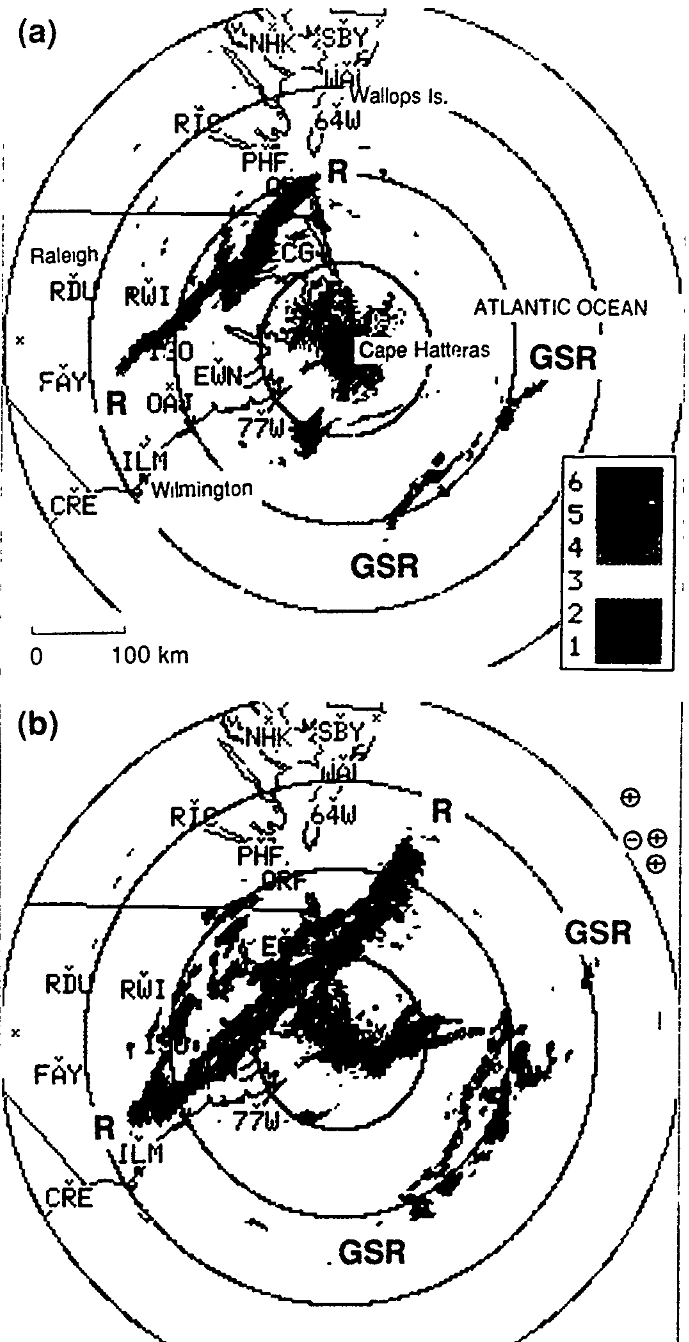


Arctic research site

Finally, two major reports issued by NSF in 1987 underscored the importance of polar research:

- *The Role of the National Science Foundation in Polar Regions* was prepared by a National Science Board committee chaired by Rita R. Colwell, Director of the Maryland Biotechnology Institute and Professor of Microbiology at the University of Maryland, College Park. The report includes contributions from 47 experts in science, research policy, and logistics. The 1, .ecommendations highlighted in the report are intended to aid the Foundation in fulfilling its responsibilities as lead agency for basic research in the polar regions.

P V Hobbs




Storm intensity levels. These color-coded levels were measured by National Weather Service radar at Cape Hatteras on 6 March 1986, at 10:21 E.S.T. (see "a") and at 12:31 E.S.T. (see "b"). Color codes 1 and 6 indicate the lightest and the heaviest precipitation, respectively. The prefrontal and the Gulf Stream rainbands are labelled R and GSR, respectively. The circles centered on Hatteras are range markers at intervals at 50 nautical miles from the cape.

● The Interagency Arctic Research Policy Committee, composed of representatives from the National Science Foundation and 11 other federal agencies, has laid out a plan (required by the Arctic Research and Policy Act of 1984) for federal support in arctic research over the next five years. Implementation of the plan will provide scientific and engineering knowledge required for national security, rational resource development with minimal adverse impacts, and improved understanding of regional and global climate change. The Committee's recommendations are outlined in the *United States Arctic Research Plan* published by NSF.

## Atmospheric Research

Since the early days of sailing, when it was called the "graveyard of ships," the area off Cape Hatteras has been recognized as a region where winter storms often intensify very rapidly. A large field experiment called the Genesis of Atlantic Lows Experiment (GALE) was centered on the Atlantic Coast of North Carolina; one of its goals was to investigate the reasons why rapid storm intensification occurs at this location. During the experiment a recurrent region of banded clouds and precipitation was identified and found to be almost stationary over the Gulf Stream.

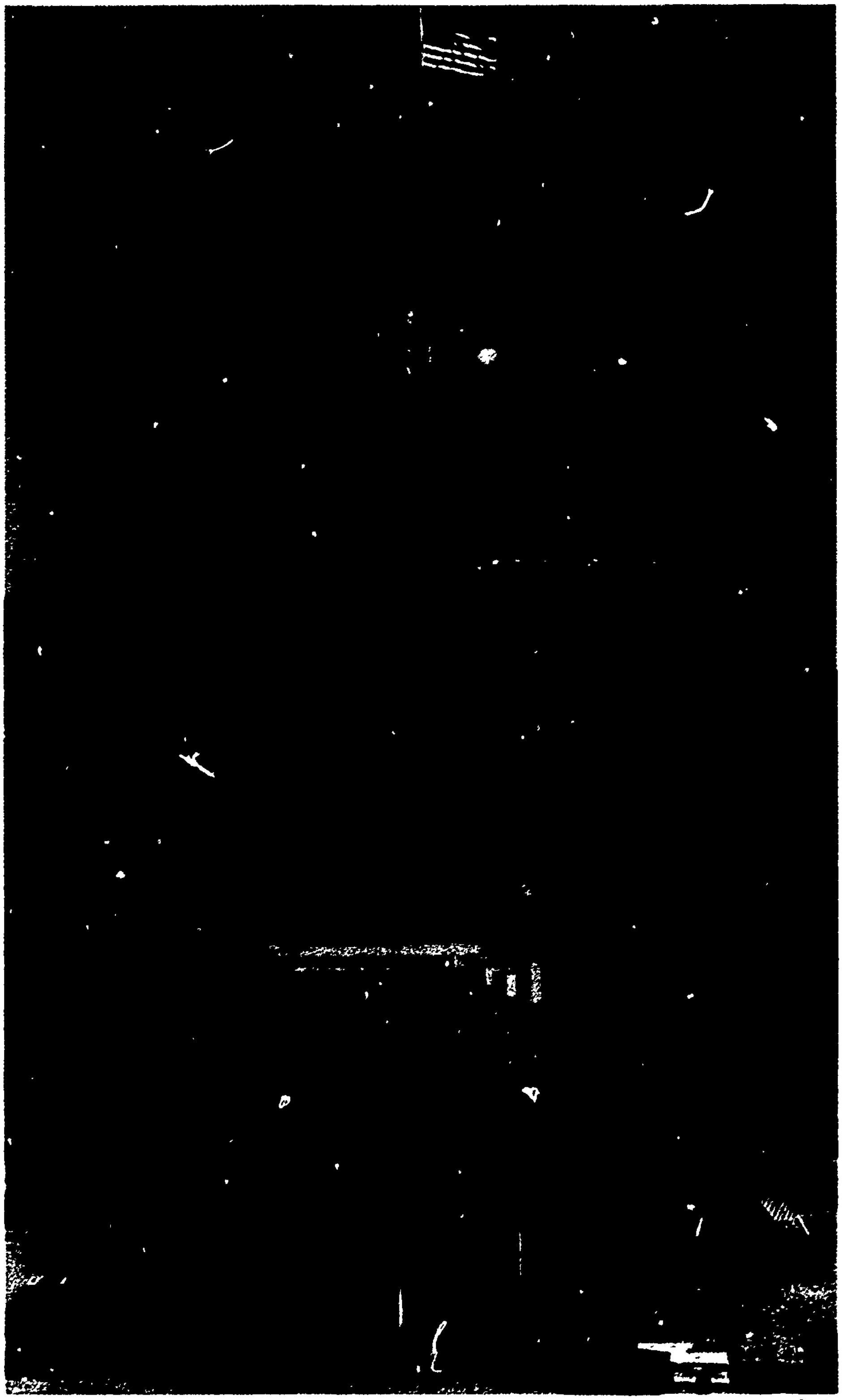
This phenomenon is attributed to large heat and moisture fluxes from the warm water of the Gulf Stream to the colder, overlying air. Indeed, the magnitude of these fluxes is comparable to what would be received from the sun on a cloudless day in summer. The full implication of this redistribution of heat and moisture is the subject of ongoing research. It is clear, however, that the intensity of this persistent rainband, as revealed by radar, indicates rainbands could play an important role in the intensification of winter storms on the East Coast.

In other atmospheric research, three complete ice cores from a subtropical region, the Dunde Ice Cap in the northeastern section of the Quinghai-Tibetan Plateau, were retrieved by a joint US-Peoples Republic of China expedition during the summer of 1987. Water samples and frozen ice cores in pristine condition were returned to the Byrd Polar Research Center at the Ohio State University and to China's Lanzhou Institute of Glaciology and Geocryology. Preliminary micropartical, oxygen isotope, and conductivity analyses of the samples indicated a strong likelihood that each ice core contains the first glacial-stage ice to be recovered from a nonpolar location. The detailed high-resolution paleoclimate record contained in these cores could be significant in calibrating the rich and diverse written record of historical climate in the Chinese region.

Finally, in the summer of 1987, scientists from the University of Illinois, using modern Lidar equipment, were working near Spitsbergen, in the Arctic Ocean. There they discovered a "hole" in the sodium layer near an altitude of 145 miles. The hole could be caused by adsorption on the ice crystals of noctilucent clouds (those that shine at night). Similar reactions of chemicals with winter ice crystals in Antarctic stratospheric clouds are thought to be responsible for the ozone "hole" over that continent (see "Highlights"). Research on the arctic phenomenon continues at this writing.

## Earthquake Research

Scientists from 11 U.S. universities have been conducting scientific experiments in a hole being drilled at Cajon Pass near the San Andreas fault in California. There they have been



**Earthquake research. At Cajon Pass, in the earthquake-prone region of the San Andreas fault in California, scientists have drilled a hole deep enough to sample the earth's crust and monitor the forces that may give early warnings of an earthquake.**

creating a deep-earth observatory to monitor the earthquake-prone area over the next several decades. The drilling project, funded principally by NSF through an effort called Deep Observation and Sampling of the Earth's Continental Crust (DOSEC), enables researchers to sample the earth's crust near zones where forces crush and stretch rock. Deformation of that crust may be one early warning sign of an earthquake, and the drilling project could help to improve predictions of these natural disasters.

The State University of New York at Buffalo is headquarters for a national center on earthquake engineering research. This center was established by Cornell, Princeton, Columbia, and Lehigh Universities; the Rensselaer Polytechnic Institute; the City College of New York; and SUNY/Buffalo. Center researchers look into ways to minimize the loss of lives and property caused by earthquakes. Among the problems they address are seismic risk levels in the eastern United States and potential hazards caused by the fact that many U.S. structures were not built with earthquake risks in mind.

As part of its prevention studies, NSF also learns from earthquakes when they occur — including the one that hit Whittier, California, in the fall of 1987. Although this earthquake was relatively small, it claimed six lives and caused property damage estimated at $125 to $250 million. And researchers detected aftershocks for several days after the quake.

By studying such events, NSF hopes to learn more about the problems caused by larger quakes and better understand the vulnerability of communities in future situations of this kind.

As part of NSF-funded research, teams of scientists were quickly dispatched to the California site. There they assessed such influences as the quake's effect on power and water lines, the occurrence of (and the ability to extinguish) earthquake-related fires, and the stability of buildings. In addition, public briefings on earthquake issues were co-sponsored by NSF and held in San Francisco, Washington DC, and Pasadena.

NSF-supported research is also underway to learn from recent earthquakes in Chile and New Mexico. More than 30 research projects seek new knowledge and a basis for further mitigating the effects of earthquakes in the United States. And in a cooperative agreement with Japan, NSF is studying design methods that will help create masonry structures that are especially resistant to earthquakes and other seismic disturbances.

### Ocean Drilling

The Ocean Drilling Program, an internationally supported effort to understand more about the earth's history through study of the ocean floor, has found surprising new details about the geography and climate of Antarctica. Sea floor sediment accumulated over a period of 50 million years at the bottom of the Weddell Sea near the South Pole revealed striking differences in ice formation between West and East Antarctica. Two months of drilling by the research vessel *Joides Resolution* also uncovered spores and pollen grains, providing new evidence that until about 39 million years ago beech trees and ferns flourished in Antarctica and the continent once had a much warmer climate.

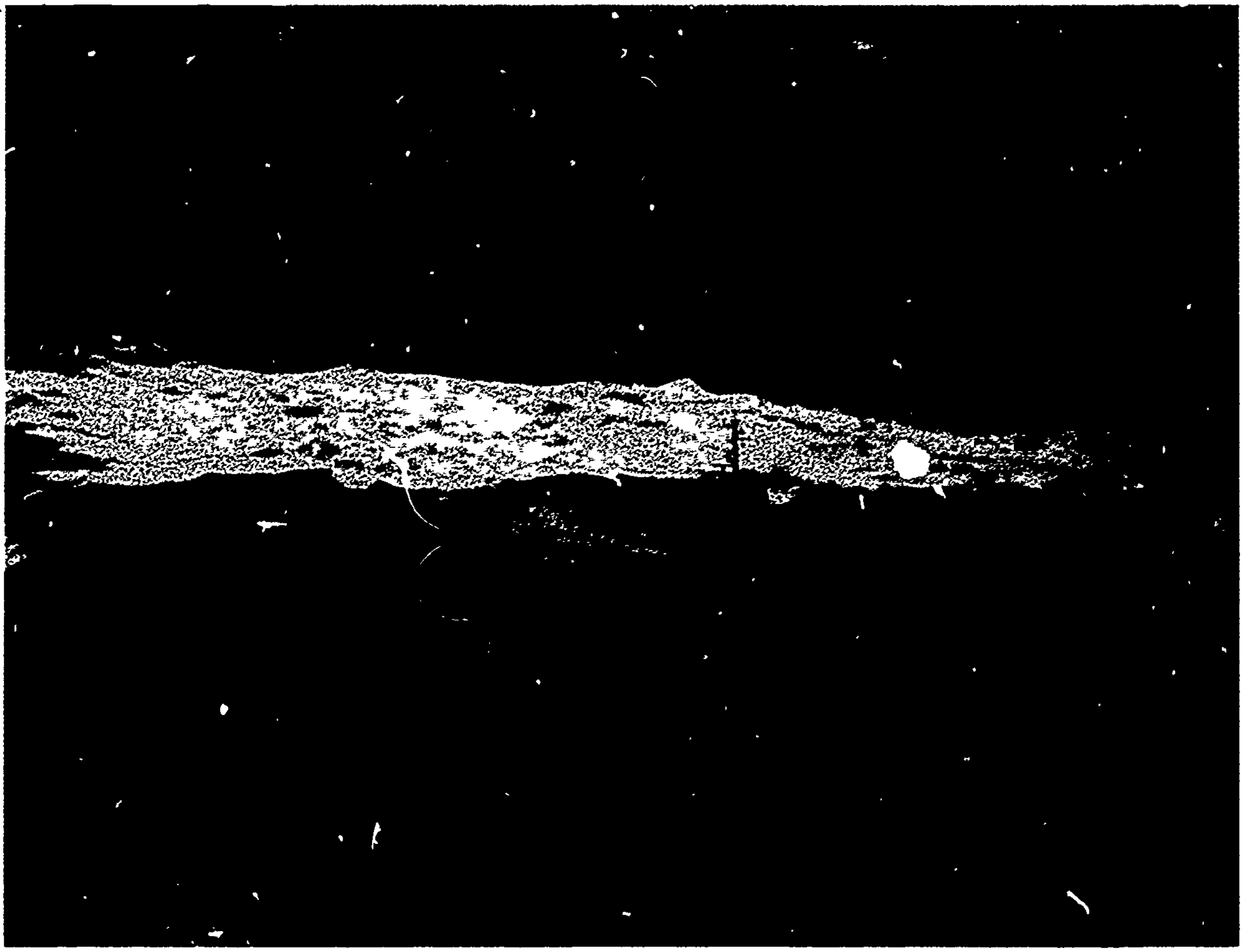
The Weddell Sea drilling, made possible only after a companion ship towed away icebergs weighing millions of tons, extracted sediment hidden below three miles of icy ocean. Analysis of sediment layers off the shore of West Antarctica dated the formation of ice sheets there to 8 million years ago, and showed that contrary to some theories, the sheet has remained intact without melting for nearly 5 million years.

In contrast, drilling off Queen Maud Land in East Antarctica, separated by a mountain range from the west land mass, revealed that ice formation there began much earlier, about 37 million years ago. And the discovery of diatom fossils, microscopic algae that can live only in sunny waters, indicates that the eastern ice sheet did not cover the entire ocean for more than 20 million years.

Micropaleontologist *James R. Kennett*, then at the University of Rhode Island, led the expedition along with marine geologist and geophysicist *Peter Barker* of the University of Birmingham in the United Kingdom. They reported that climate changes in Antarctica can be inferred from detailed studies of the ocean floor. For example, melting ice sheets cause rivers to form; the rivers in turn deposit sand and gravel on the continental shelf. Periodically, these deposits fall to the ocean floor, leaving a permanent record of events that occurred millions of years ago.

The Ocean Drilling Program is funded by NSF and several international partners (Japan, France, United Kingdom, West Germany, Canada, and the European Science Foundation). Management is by contract to the Joint Oceanographic Institutions (JOI) Inc. and subcontracts to Texas A&M University and the Lamont-Doherty Geological Observatory.

Texas A&M University



Ice Work. *Maersk Master,* ice-support vessel for the ship *Joides Resolution,* tows an antarctic iceberg weighing nearly 12 metric tons.

6

## COMPUTER SCIENCE

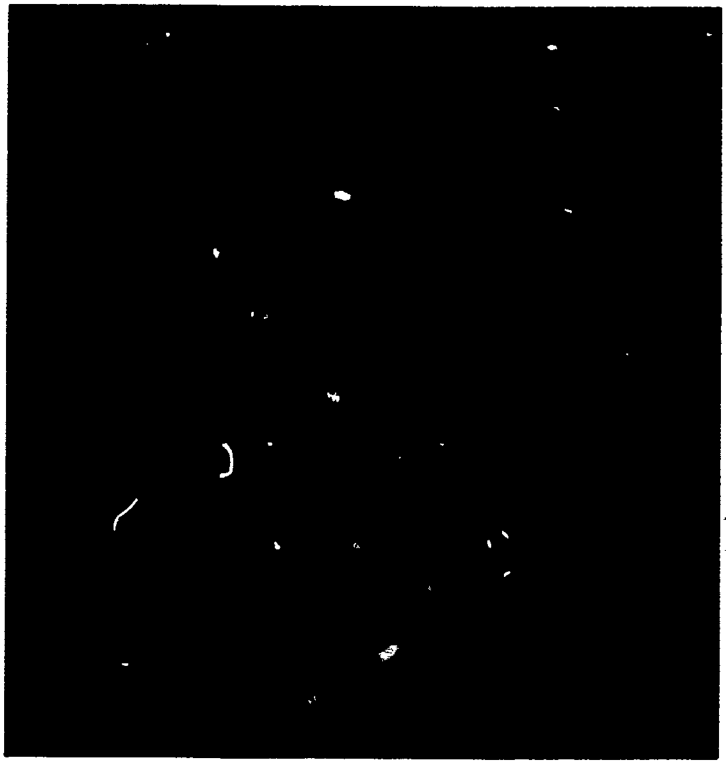
### Cross-Disciplinary Research

The use of computers in research has become ubiquitous. Computers allow scientists to simulate experiments impossible to perform in the laboratory, and they serve as calculators for data that could not otherwise be analyzed.

Recognizing these and other applications, NSF has launched a new funding program that stretches across all disciplines in encouraging investigators to use computers in solving research problems. While many universities already have strong programs in computer research, most do not foster interdisciplinary studies. In addition to emphasizing collaborations among scientists, engineers, mathematicians, and computer specialists, the NSF program (called Opportunities for Research in Computer Science) also supports training of advanced students in state-of-the art computer techniques.

### Robot Language

Robot programming languages — ways to describe and manipulate complex spatial and temporal relationships — present both a major intellectual challenge and an opening to new technical and economic frontiers. One of the most exciting pieces of research in this area is that of *John Hopcroft* of Cornell University. Through a simulation environment, Hopcroft has developed a new system that would allow a user to design, test, and evaluate a robotic system before it is built. By reducing the amount of prototyping time, a fully developed capability of this sort would significantly accelerate the transformation of a robot from an idea into a functioning production device.



**Gripper. A simulated three-fingered robot hand holds an object in a Cornell University robotics research effort.**

Hopcroft's research group has developed a modeling system that allows objects to be built and modified quickly and easily. The team has produced an electronic model of a three-fingered gripper developed by Stanford University and the Jet Propulsion Laboratory. The group also has developed electronic models of variations on the gripper.

Through NSF-funded projects such as this one, the field of robotics has evolved from a strictly mechanically-based endeavor to a science of representing, manipulating, and reasoning about physical objects with a computer. The mechanical aspects of kinematics and dynamics are still important, but other exciting areas of research are now open. Robotic systems can be seen as not just a replacement of labor, but as an intelligent interface between perception and action, and as a new form of human/machine partnership.

## Experiment in Electronic Mail

The primary form of communication among scientists and engineers is still paper documents. Although the use of electronic mail — messages, reports, and graphics sent via computer — speeds communication and can enhance the work of researchers collaborating on written material, scientists have sometimes faced obstacles in adopting the new methods. One obstacle is that the incompatibility of different electronic word processing and desktop publishing systems makes communication between people with different machines or editing environments nearly impossible.

To help improve electronic communication among different computer systems, NSF launched EXPRES, Experimental Research in Electronic Submission. The project seeks to develop a system that would handle electronically all aspects of the NSF grant proposal process, including document submission and reviewer comments. Once such a model system is developed, researchers hope to extend its use to more general scientific communications. At this writing, NSF supports EXPRES projects at Carnegie Mellon University and the University of Michigan.

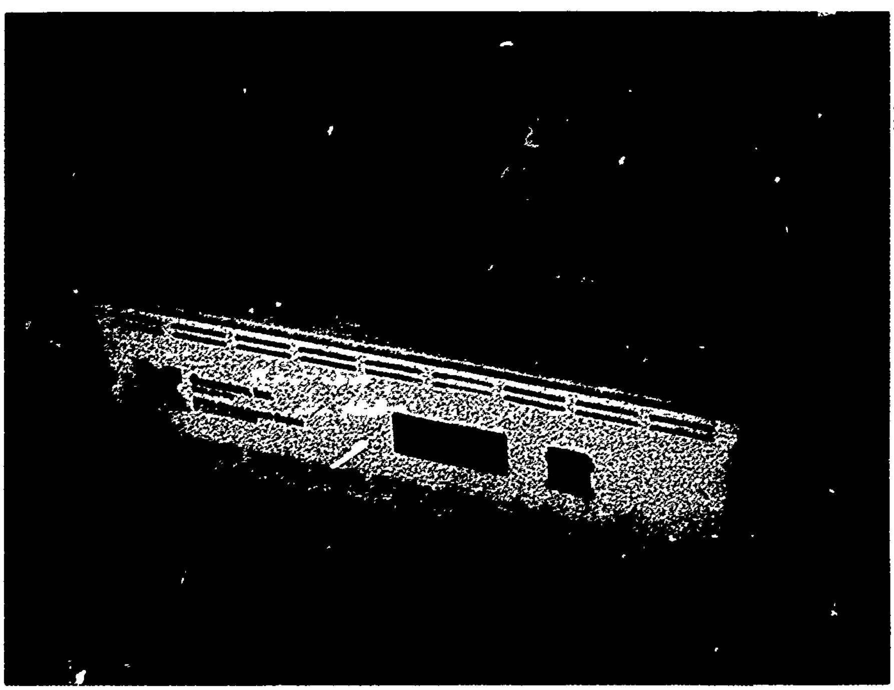
Internally, NSF has implemented a Foundation-wide electronic mail system known as NOTE. The NOTE system has direct connections to the major academic and research networks and thus provides enhanced communication not only between employees at headquarters but between them and grantees and reviewers in the research community. In addition to electronic mail, NOTE provides an electronic bulletin board and online access to NSF manuals and documentation. Some of the present and planned uses of the system include electronic dissemination of NSF policy and program announcements and electronic receipt of proposal information and reviews.

## Technology Transfer: From Computer Lab to Industry

In recent years a number of computer programs developed through NSF-supported research have made their way from academia to the marketplace. In some cases researchers have set up companies that collaborate with universities to improve upon and market software that might otherwise never reach its intended audience.

At the University of Illinois, computer scientist *David Kuck* and his associates formed Paracomp, a company that tailors software developed on the campus supercomputer so that it can be easily used by businesses and research institutions. The computer programs have application to weather prediction; airplane design; structural mechanics, including the stability of bridges and the safety of automobiles; and analysis of field theories that underlie the fundamental forces of physics.

Another collaboration between university and industry involves the work of University of Utah computer scientist *Lee A. Hollaar*, who developed a computerized text-searching system. Hollaar's system improves upon search programs already on the market because it can electronically copy the text it locates into other documents. This feature is particularly useful for lawyers, who often need to cite the wording of a precedent-setting case in court documents. In addition, the system has a special processor, tailored to the search task, that significantly reduces search time. It is also easily expandable, so that extra computing power is available as the size of the text to be searched increases.


University of Utah

**Technology transfer. NSF supported Lee Hollaar, a computer scientist who developed the computerized text-searching system pictured here.**

In 1983, Hollaar set up Contexture Inc, a company that handles the commercial development, manufacturing, and licensing of the search system, which was developed with NSF funds at both the University of Illinois and the University of Utah. According to Hollaar, the company immediately developed packaging and completed tests required by the Federal Communications Commission to take the system from the university workbench to a prototype that could attract potential users. In addition, based on the preliminary research funded by NSF, another government agency (the Central Intelligence Agency) sponsored additional research to expand the search system for its own use

## ENGINEERING

For the 20 years ending in 1985, NSF provided funding for 31 of 46 engineering advances considered the most significant by representatives of six professional engineering societies. NSF was also cited more often than any other funding source in research papers associated with 10 specific advances. These advances were in such fields as robotics, ceramics, composite materials, and solid-state circuits.* Engineering research supported by the Foundation in 1987 continued this distinguished trend, as shown in the examples that follow.

### Engineering and Biotechnology

Monoclonal antibodies, the molecules that destroy specific types of cancer cells and other disease-causing agents, are just one of the vital biological substances made possible by advances in molecular biology, genetics, biochemistry, and related fields. In order to address problems encountered in mass producing these substances and to bolster university training of people involved in large-scale production, NSF's engineering directorate has a program in biotechnology that ties together research from several disciplines. Topics include, but are not limited to, improved methods of culturing normal, exotic, and genetically altered cells, development of new uses of proteins and other biological materials in the design of large biological reactors, techniques to separate or purify large quantities of dilute and impure solutions of complex substances, and methods to monitor the metabolism of cells immersed in culture.

### Engineering-Materials Research Link

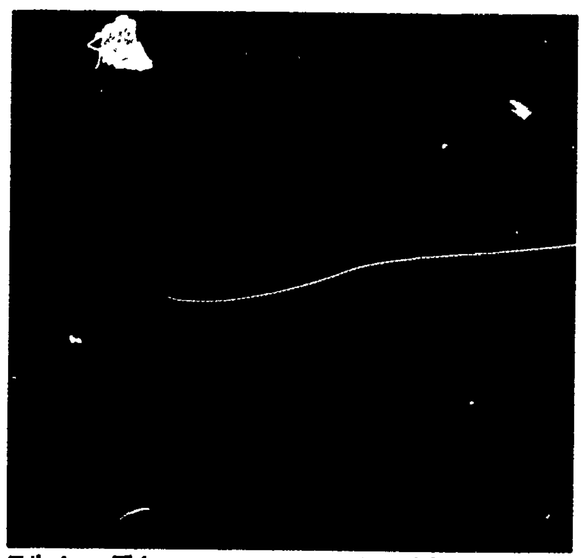
New demands for complex materials with precisely controlled chemistry, shapes, and properties have led to worldwide competition in manufacturing materials. To help meet this demand, NSF announced a joint effort by its Directorates for Engineering and for Mathematical and Physical Sciences; their goal is to strengthen U.S. research in materials processing and related activities.

Processing generally involves the transformation of raw materials into useful, finished objects. One example is the transformation of graphite compounds into composite, lightweight materials needed for aircraft such as the *Voyager* spacecraft, which has circled the globe. And the processing of high-temperature superconducting materials from ceramic compounds (see "Highlights") has become a major research endeavor.

The NSF initiative encourages collaborations with industry because of the concentration of expertise there, industry's economic stake in results, and its available facilities and research instruments. Collaborations among different disciplines are also important because materials research spans the full breadth of science and engineering, including solid-state physics, fluid mechanics, and mechanical engineering.

### Tribology

Tribology is the study of surfaces that move or slide against each other. Ball bearings and gears in an automobile are examples of tribological components. Scientific research in the field of tribology is generally aimed at providing a mechanistic understand-



**Tribology. This computer-generated model is used to study the contact dynamics and tribological performance of a mechanical face seal.**

*Source *National Science Foundation Support for Significant Advances in Fundamental Engineering Research, as Shown in Publication Acknowledgments 1965-1985*, NSF Program Evaluation Staff, Office of Budget and Control ing of the phenomena that occur at the moving contacts.

With new studies delving into the chemical interactions at surfaces, the development of models to predict the behavior of these materials, and related inquiries, NSF has increased support for its tribology program. Included in 1987 was a summer internship designed to draw faculty to such research. The program gave faculty members who had never investigated tribology but were experts in related areas the opportunity to learn about the field.

## Neuroengineering

The brain is the oldest and most powerful computing machine we know, and its communication system is far more puzzling than that of the most advanced supercomputer. What fundamental processes underlie the complexities of information processing in the brain? Researchers look for biological analogues inside assemblages of transistors and diodes, electronic components that are the basis for computer circuitry. Conversely, networks of electronic circuits that mimic the pattern of nerve cells inside the brain are leading to experimental components that may revolutionize computer science. These studies offer potential advances in computers that recognize and respond to human speech, in creating more autonomous robots, and in computer vision systems. To help foster research in this relatively new branch of science, known as neuroengineering, NSF began a new funding program in FY 1987.

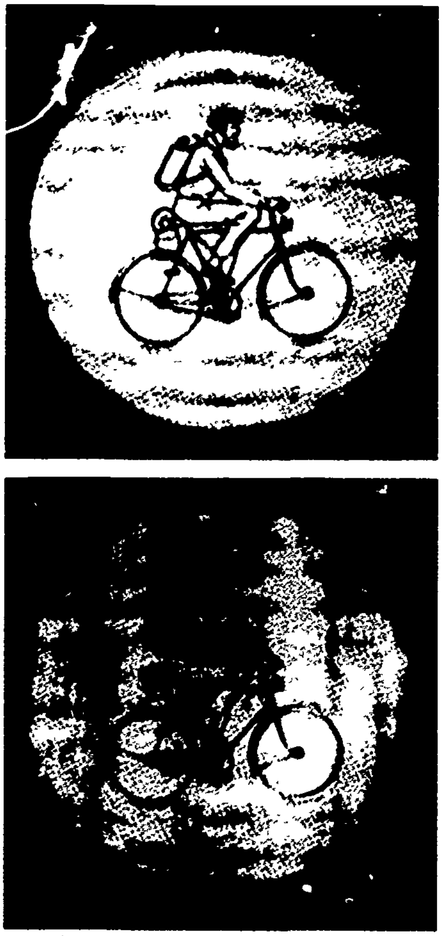
With the help of NSF funds, *Christof Koch* and his colleagues at the California Institute of Technology study the cat's eye to understand how nerve cells in the retina detect motion. Their research, in collaboration with *Tomaso Poggio* at the Massachusetts Institute of Technology, has uncovered an underlying biophysical mechanism for motion detection that may be involved in other types of nerve cell operations in the brain, including depth perception. In addition, their investigations, which suggest that each nerve cell acts like a computer chip containing hundreds of transistors, has application to robot vision systems and the development of automated television cameras.

Other neuroengineering research has focused on neural networks, the complex circuits that scientists design to mimic the sophisticated decision making of the human brain. Computer chips and electronic wire are the usual components of these networks, but now researchers have devised an alternative model: circuits that replace wire with lasers and mirrors and use light-sensitive crystals, rather than computer chips, to convey information and make decisions.

*Dana Anderson* at the University of Colorado at Boulder and *Jack Feinberg* at the University of Southern California in Los Angeles collaborated on an optical circuit that memorizes the shape and position of an object. A three-dimensional hologram of the object forms inside a crystal in the circuit, but the image quickly fades unless the object moves or changes position. For example, a Walt Disney animated film run through the circuit, known as a Novelty Filter, is visible only when the characters move or the scenery changes; if Mickey Mouse temporarily stands still, he disappears from the screen. Bacteria under a microscope connected to the Novelty Filter are seen only as they slither back and forth across the slide.

The filter instantly tracks the new position of objects as they move and may have potential applications to optical computing.

Another experimental circuit built by Anderson relies on laser light that travels through a loop containing mirrors and two crystals. One crystal uses the light to optically store a variety of simple images; the other crystal acts as an amplifier. When a light beam shines a fragment of any of the stored images into the circuit, this action triggers the circuit to search out and retrieve the entire stored image. For example, if the crystal stored the images of a cat and a dog, shining the image of the cat's tail would trigger the crystal to retrieve the full image of the cat. According to Anderson, this type of pattern recognition suggests some of the complex actions associated with the brain and human memory.



**Novelty filter. Dana Anderson and Jack Feinberg collaborated on an ingenious new optical circuit that memorizes the shape and position of an object. A three-dimensional image of the object forms in the optical circuit—known as a "Novelty Filter"— but the image quickly fades unless the object moves or the background scenery changes, as seen in these two photos.**

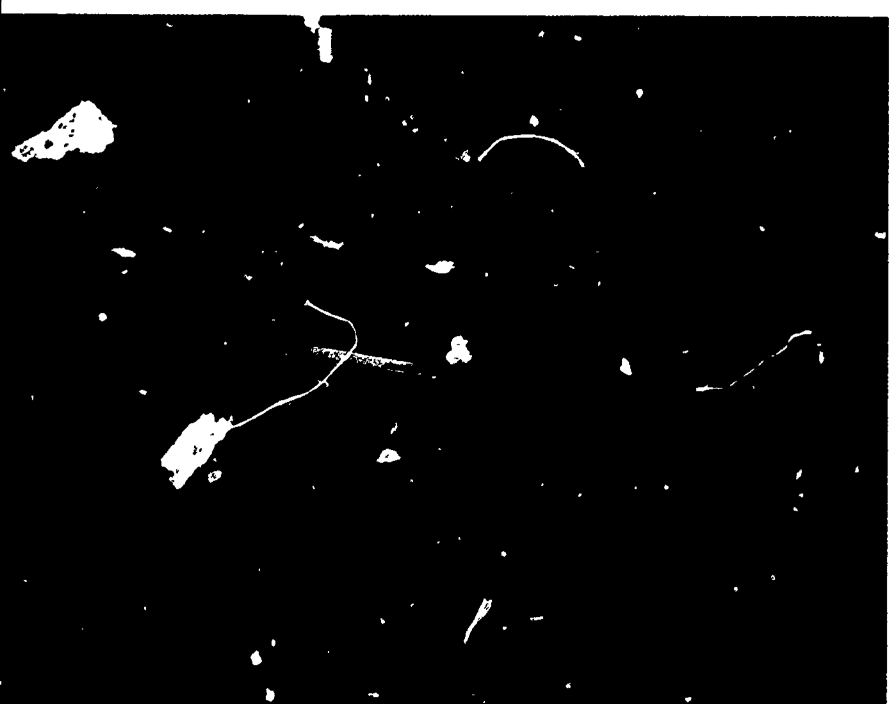
## Research in Engineering Design

Thoughtful study of the design process can sometimes correct problems in a product before it is manufactured, suggest the most appropriate materials for its manufacture, and dramatically decrease production costs. In addition, computer programs based on expertise gleaned from successful design projects can aid the design of new products. NSF support focuses on developing scientific methods for engineering design and establishing a formal discipline in this relatively new area of study.

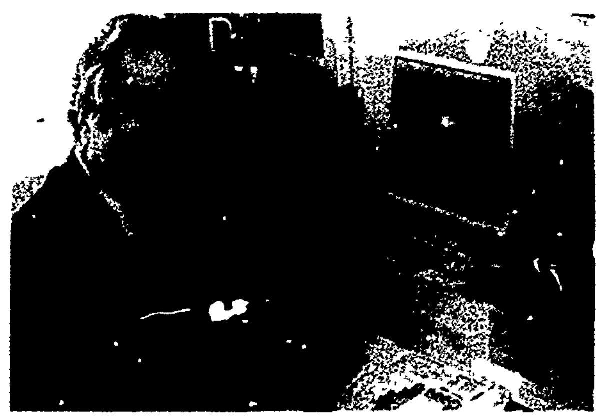
Beginning with a project for a design class taught at Stanford University, engineer *Mark Cutkosky* and his collaborators have developed the basics of an automated manufacturing system. The aim of their computerized system is to keep the designer in daily contact with staff involved in all parts of the manufacturing process, allowing the manufacturing resources of a specific company to be taken into account in planning a product. The model system also enables others in a company to suggest design changes — even if those employees work across the country. Engineering students have tested their original designs for manufactured metal parts on the system, honing the design skills learned in class. According to Cutkosky, students have found that their design style is creatively altered by interaction with the computer.

*Myron Fiering* at Harvard University has used computer techniques for another aspect of engineering design. the analysis of classic design failures to understand how errors can be anticipated and designs made sufficiently flexible to survive unexpected flaws or stresses.

Aided by a computer, Fiering and his graduate student, *Benito Villamarin*, grouped some 30 flawed designs, as well as designs that withstood unusual stresses, according to common themes. The researchers then began to develop a computer program, designed to run on an ordinary personal computer, that uses the analysis of flawed designs to indicate potential errors in new plans.



Mark Cutkosky, Stanford University



Myron Fiering

**Computerized manufacturing. A machine part is drilled on a special platform that senses the forces and torques exerted on the part in all directions. The goal is to gather information from the manufacturing process as it occurs, in order to update or fine-tune the manufacturing knowledge base and to suggest changes in design. This work was done by Mark Cutkosky and his team at Stanford University.**

Boyd C Paulson, Stanford University

**Construction automation: Computerized model of a machine that moves earth. The machine is connected to a microprocessor that allows it to adjust automatically for the weight of the load, type of material, and other day-to-day variations encountered at the construction site. This is an example of work done by Boyd C. Paulson and Raymond Levitt at Stanford University.**

### Automated Construction

Robots digging tunnels, computers that test design plans, artificial intelligence methods for tracking progress at the job site: such developments appear to signal the construction industry's future. If so, U.S. companies may be losing their competitive foothold. Although the industry is an important and lucrative business—American construction companies earn more than $380 billion a year and employ some 5.5 million workers—productivity of U.S. companies has remained flat and the industry spends less than 0.4 percent of sales on research and development. Japan and other countries are taking an increasing share of the business. A new program begun by NSF's engineering directorate seeks to boost the competitive position of U.S. firms through research in automated or computer-integrated construction.

In recent years, NSF has awarded eight grants to investigate use of the computer in planning, organizing, and building skyscrapers and other large structures. Some examples:

- At the University of Texas at Austin, engineers led by *Alfred E Traver* collaborated with Bechtel, Inc. to explore the way pipes could be selected and fit together at a construction site with the aid of computers and a specially designed robot.
- Researchers at the University of Maryland, Virginia Polytechnic Institute, and Pennsylvania State University have studied various ways to (1) automate activities on construction sites and (2) provide an open, interactive data environment for engineering design of buildings, construction processes, and facilities management after construction has been completed.
- Engineers under the direction of *Irving J. Oppenheim* at Carnegie Mellon University have explored methods to automate digging at construction sites.
- At Stanford University, research teams directed by *Boyd C. Paulson* and *Raymond Levitt* considered instrumentation for monitoring equipment safety and production. One of the Stanford projects, known as "Sight Plan," sought artificial intelligence methods to design the layout of a model work site, coordinate workers or robots on the job, keep track of supplies, and record and make adjustments for the continually changing nature of the construction project.

## INTERNATIONAL ACTIVITIES

### China

In an effort to boost international cooperation, NSF sponsors a number of research activities and agreements with other countries. In 1987, for example, NSF sponsored a joint seminar with China on the subject of advanced ceramic materials, anticipating continued cooperative research in this area Such joint research allows U.S. scientists to forge ties with their Chinese counterparts in areas of mutual scientific interest.

### Yugoslavia

An NSF-sponsored cooperative project in theoretical physics between the University of Zagreb and Purdue University has spurred development of a new theory about nature. The theory postulates a fifth force — the hypercharged force — that acts at short distances against the tug of gravity. The theory, with implications that would greatly alter our view of the universe and its origins, has stimulated widespread interest and experimentation in the United States and abroad.

### India

Scientists from Purdue University and the Indian Institute of Science, Bangalore, have joined forces to develop and study high-temperature superconductors (see "Highlights") made of metal oxides. The researchers designed new methods for synthesizing the oxides; some 30 technical papers on their work have appeared in major international journals.

### Japan

Through a new collaborative research program with Japan, NSF is helping to advance computer research and spur development of the next generation of computers in the international community. The Foundation and the Japanese Institute for New Generation Computer Technology (ICOT) jointly developed a program that allows U.S. scientists and engineers to conduct research at ICOT. Under the joint agreement, which began in 1987, ICOT opens its doors each year to up to three U.S. scientists selected and supported by NSF.

**Example of international work: Researcher measures nutrient flow in a study of nutrient cycles in a tropical rain forest system. This project took place near the joint border between Brazil, Colombia, and Venezuela.**

## New International Information Office

In March 1987, NSF established a new information and analysis office to monitor technical developments in major areas of the world and to analyze their impact. Eventually this office plans to distribute—both in print and electronically—its information products to U.S. scientists and engineers. Examples include some 120 studies on technical advances and policy trends in Japan.

Also underway is a pilot program (developed with the U.S. Departments of State and Commerce) that involves selected academic, government, and industrial users nationwide. The aim of this study is to determine the most effective format, content, and public distribution method, as well as appropriate user groups, for U.S. government reports on foreign science and technology developments.

The new office is part of NSF's Directorate for Scientific, Technological, and International Affairs.

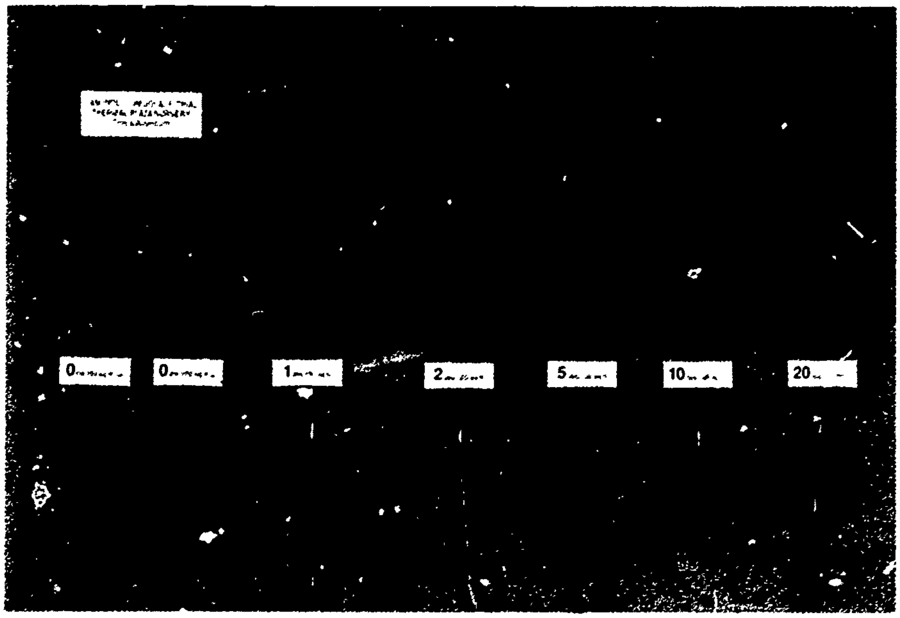
## SMALL BUSINESS GRANTS

Small businesses involved in scientific and technological innovations often cannot support the research needed to develop the next generation of state-of-the-art devices. NSF's Small Business Innovation Research (SBIR) Program funds high-quality research at these companies. In 1987, NSF awarded 151 "Phase I" grants that provide firms with up to $40,000 for six months to explore innovative research ideas. The most promising projects to emerge from Phase I are awarded up to $200,000 for two additional years of NSF-supported research. Private investors then take over during the third and final stage, which involves product development, manufacturing, and marketing efforts.

Products resulting from SBIR-funded research include:

- Plant-derived insecticides, as well as new plant gene-mapping techniques, by Native Plants Inc (NPI) of Salt Lake City. NPI raised $64 million in private investment and increased employment from 40 to 450 since receiving its first SBIR award in 1980.
- Improved catalysts for continuous flow fermentors, which use microbes for rapid production of genetically engineered protein, by Verax Corporation of Lebanon, New Hampshire. Since receiving awards in 1982 from the Foundation's SBIR program and from the National Institutes of Health, the company has increased its size from 12 to 87 employees.

See also the "Highlights" section of this report for another example of SBIR support.




**Small business innovation: an innoculation trial at Native Plants, Inc., Salt Lake City, Utah. In this trial of a mycorrhizal plant growth system a symbiotic association between a nitrogen-fixing fungus and the root system enhances growth.**

**Verax processor. Another small business effort supported by NSF resulted in equipment such as this processor, which is based upon the development of microporous beads that serve as the growth surface for cells.**