Research Support Activities

Support of fundamental research in all fields of science is a major function of the National Science Foundation and is the primary responsibility of the Research Directorate. Limited support for projects of an applied nature is also provided through the Research Directorate. These responsibilities are carried out mainly through grants to academic institutions where research also contributes to education in the sciences. Principal mechanisms for research support are as follows:

- Grants to institutions in support of individual scientists or small groups of scientists pursuing scientific investigations deemed to have outstanding potential for the development of new scientific knowledge.
- Grants in support of the International Biological Program and the Global Atmospheric Research Program. (These programs, administered by the Research Directorate, are described with other National and International Programs on pages 38–39 and 43–44.)

Supplementing scientific research project grants through which most of the Directorate's funds are distributed, limited support is also provided to assist in:

- The purchase of specialized research equipment.
- Construction or acquisition of specialized research facilities.
- Defraying the costs of travel of individual scientists to selected scientific conferences.
- Support of dissertation research in the social sciences and certain other sciences involving extensive field work.

In addition, the Foundation supports five National Research Centers for the conduct of research in astronomy and the atmospheric sciences. Administration and funding of these centers are discussed in the chapter on National and International Programs. Scientific aspects of their activities will be found in this chapter under the appropriate discipline.

Scientific Research Support

The Foundation awarded 4,329 grants for the support of individual research projects in fiscal year 1971 amounting to $174.6 million. Comparable figures for fiscal year 1970 were 3,817 grants for a total of $161.7 million. Table 1 gives the distribution, number, and amount of grants according to field of science for fiscal years 1969, 1970, and 1971. Of all the actions taken by the Foundation on research project proposals in fiscal year 1971, 46 percent were awards as compared to 47 percent in 1970. Grants were awarded to 419 institutions, including 304 colleges and universities, in all 50 States, the District of Columbia, and Puerto Rico. Ninety-four percent of the funds went to academic institutions. Of these, 214 received two or more research grants, and 124 received $200,000 or more. The average distribution for approved cost items on the 4,329 research grants made in fiscal year 1971 is shown in table 2.

It is estimated that NSF support of research that could properly be classified as being applied totaled approximately $42 million in 1971. This was an increase of approximately $10 million over the previous year. Applied research is supported principally under the NSF program of Research Applied to National Needs, which represents a consolidation of NSF's major problem-focused research efforts. These projects include Weather Modification, Earthquake Engineering, Enzyme Technology, and research efforts previously supported in Interdisciplinary Research Relevant to Problems of Our Society. Some applied research is also supported under the Foundation's Scientific Research Project Support and National and International Programs and at the National Center for Atmospheric Research.

Table 1
Scientific Research Projects
Fiscal Years 1969, 1970, and 1971
(Dollars in millions)

	Fiscal year 1969		Fiscal year 1970		Fiscal year 1971	
	Number	Amount	Number	Amount	Number	Amount
Astronomy:						
Solar System Astronomy		.57		.58		.45
Stars and Stellar Evolution		1.70		1.45		1.59
Stellar Systems and Motions		.72		.77		.52
Galactic and Extragalactic Astronomy		2.48		1.26		3.17
Astronomical Instrumentation and Development		1.35		1.74		.69
Subtotal	125	6.82	108	5.80	135	6.42
Atmospheric Sciences:						
Aeronomy		1.65		1.69		2.21
Meteorology		4.30		3.95		4.58
Solar-Terrestrial		2.25		2.28		2.37
Subtotal	116	8.20	118	7.92	143	9.16
Biology:						
Cellular Biology		9.28		8.68		8.89
Ecology and Systematic Biology		7.96		8.60		8.50
Molecular Biology		9.88		9.76		10.73
Physiological Processes		10.04		9.53		9.68
Psychobiology		4.02		4.30		5.56
Subtotal	1,173	41.18	1,072	40.87	1,369	43.36
Chemistry:						
Chemical Analysis		1.48		1.71		2.00
Chemical Dynamics		4.16		3.58		3.56
Chemical Thermodynamics		1.56		1.86		2.39
Quantum Chemistry		3.54		3.40		3.54
Structural Chemistry		3.22		2.80		3.11
Synthetic Chemistry		3.90		4.05		4.27
Subtotal	484	17.86	449	17.40	488	18.87
Earth Sciences:						
Geology		1.31		1.42		1.52
Geochemistry		3.31		3.07		3.05
Geophysics		3.30		3.36		3.43
Subtotal	200	7.92	169	7.85	225	8.00
Engineering: [4]						
Engineering Chemistry		2.73		2.82		2.92
Engineering Energetics		2.94		2.86		2.70
Engineering Materials		3.23		3.29		3.88
Engineering Mechanics		6.39		6.55		5.57
Engineering Systems		3.00		[1]		[1]
Special Engineering Programs		.98		1.17		.98
Electrical Science and Analysis		- 0 -		- 0 -		1.35
Subtotal	491	19.27	463	16.70	425	17.40
Mathematics:						
Algebra and Topology		4.39		4.49		4.42
Analysis, Foundations, and Geometry		4.37		4.34		4.69
Applied Mathematics and Statistics		3.94		3.83		3.82
Subtotal	462	12.70	489	12.66	535	12.93
Oceanography: [2]						
Biological Oceanography		3.13		3.66		3.88
Physical Oceanography		2.16		2.07		2.69
Submarine Geology and Geophysics		2.55		3.18		3.35
Support, Ship Operations		8.64		[3]		[3]
Subtotal	280	16.48	218	8.91	235	9.92
Physics:						
Atomic, Molecular, and Plasma Physics		2.46		2.72		2.75
Elementary Particle Physics		11.53		11.24		10.31
Nuclear Physics		8.01		6.46		9.26
Solid State and Low Temperature Physics		4.61		4.42		4.60
Theoretical Physics		3.73		3.34		3.79
National Magnet Laboratory		- 0 -		- 0 -		.40
Subtotal	283	30.35	245	28.18	290	31.11

Table 1—Continued
Scientific Research Projects
Fiscal Years 1969, 1970, and 1971
(Dollars in millions)

	Fiscal year 1969		Fiscal year 1970		Fiscal year 1971	
	Number	Amount	Number	Amount	Number	Amount
Social Sciences:						
Anthropology		3.42		3.48		3.50
Economics		4.29		4.35		4.83
Geography		.19		.48		.65
Sociology and Social Psychology		3.29		3.35		3.73
Political Science		1.28		1.19		1.34
History and Philosophy of Science		.87		.83		.76
Special Projects		1.90		1.74		2.58
Subtotal	474	15.24	459	15.42	484	17.39
Total	4,088	176.02	3,817	161.71	4,329	174.56

[1] Included in National and Special Research Programs for FY 1970 and 1971
[2] Includes marine biology
[3] Included in National and Special Research Programs for FY 1970 and 1971
[4] Transfer of Program elements to Research Applied to National Needs (RANN) accounts for FY 1971 decrease in funding.

Table 2
Scientific Research Projects
Average Distribution of Funds by Type of Expenditure
Fiscal Years 1969, 1970, and 1971

	Fiscal Year 1969		Fiscal Year 1970		Fiscal Year 1971	
	Amount	Percent of total	Amount	Percent of total	Amount	Percent of total
Professional Personnel						
Faculty	$ 6,296	14.5	$ 6,758	15.4	$ 6,560	15.0
Research Associates	2,822	6.5	2,940	6.7	2,668	6.1
Research Assistants	6,687	15.4	6,275	14.3	5,510	12.6
Other Professional	2,345	5.4	2,150	4.9	2,274	5.2
Total Professional Personnel	18,150	41.8	18,123	41.3	17,012	38.9
Other Personnel	3,039	7.0	3,467	7.9	3,499	8.0
Fringe Benefits	1,433	3.3	1,492	3.4	1,618	3.7
Total Salaries and Wages	22,622	52.1	23,082	52.6	22,129	50.6
Permanent Equipment	3,039	7.0	2,677	6.1	2,756	6.3
Expendable Equipment and Supplies	3,300	7.6	3,028	6.9	3,149	7.2
Travel	1,216	2.8	1,273	2.9	1,356	3.1
Publication and Printing	608	1.4	658	1.5	612	1.4
Computing Costs	1,389	3.2	1,360	3.1	1,356	3.1
Other Costs	1,738	4.0	2,019	4.6	2,536	5.8
Total Direct Costs	33,912	78.1	34,097	77.7	33,894	77.5
Indirect Costs	9,509	21.9	9,786	22.3	9,840	22.5
Total Average Grant	$43,421	100.0	$43,883	100.0	$43,734	100.0

Table 3
Specialized Research Facilities and Equipment
Fiscal Years 1969, 1970, and 1971
(Dollars in millions)

	Fiscal Year 1969		Fiscal Year 1970		Fiscal Year 1971	
	Number	Amount	Number	Amount	Number	Amount
Astronomy	5	$0.324	5	$0.190	3	$0.250
Atmospheric Sciences	8	.298	4	.199	5	.290
Biological and Medical Sciences	34	.880	11	.918	22	.977
Chemistry	57	1.700	63	1.697	58	1.700
Earth Sciences	0	0	3	.103	2	.115
Engineering	26	.880	28	.600	30	.696
Oceanography	1	1.397		[1]		[1]
Physics	25	1.300	12	2.499	5	1.500
Social Sciences	2	.438	1	.298	6	.272
Total	158	$7.216	127	$6.504	131	$5.800

[1] Included in National and Special Research Programs for FY 1970 and FY 1971

Specialized Research Facilities and Equipment

In fiscal year 1971, $5.8 million was awarded to institutions to assist in the purchase of specialized facilities and equipment in biology, astronomy, earth and atmospheric sciences, physics, chemistry, engineering, and the social sciences. (Computing and oceanographic facilities are discussed in the following chapter under National and International Programs.) Distribution of funds over a 3-year period will be found in table 3. The following examples illustrate the nature of this support.

In fiscal year 1971, approximately $1 million was made available to fund a major expansion of the experimental area at the NSF-supported 10 GeV electron synchrotron at Cornell University. The Cornell electron synchrotron is the highest energy long-duty-cycle electron accelerator in the world, and the many novel types of experiments made possible by this accelerator have led to very heavy demands on the use of the experimental area by scientists at Cornell and other universities. Other university physics projects supported during the past fiscal year include the accelerator laboratories at Stanford University and the Indiana University where major equipment was provided in a continuing buildup of experimental facilities.

A grant to the University of California at Berkeley assisted in the purchase of a radio telescope with high angular resolution to operate at centimeter and millimeter wavelengths. The telescope will be a precise 20-foot antenna, mounted in such a way that it can be used later as part of an interferometer. The telescope will operate from 2 to 16 millimeters and will be equipped with a 128-channel spectrometer. The problems studied with such an instrument range from planetary to galactic and extragalactic research. The facility will be placed at the Hat Creek Observatory in northern California.

In support of social science research, a grant of $181,000 to Haskins Laboratories in New York provided for the assembly of a hardware-plus-software computer system for on-line experimentation with natural speech. The completed system will permit scientists associated with Haskins Laboratories and nearby universities to conduct research on important questions about the perception and comprehension of spoken language and language learning. Practical applications are envisaged to language teaching, man-machine communication, machine control systems, and reading aids for the blind.

The biotron at the University of Wisconsin, constructed with the help of Foundation grants, was dedicated in 1971, consummating an extensive development and construction period. The biotron permits the maintenance of animals and plants under controlled environmental conditions, and provides for programmed changes in environmental parameters. A similar laboratory, also constructed with the help of Foundation grants—but primarily for plant studies—has been in operation in the Research Triangle of North Carolina for a little over 2 years. Both the biotron in Wisconsin and the phytotron in North Carolina operate as regional facilities and are intended to serve the increasing need to validate ecological concepts developed in the field by controlled experiments in the laboratory.

MATHEMATICAL AND PHYSICAL SCIENCES

Because new knowledge in the mathematical and physical sciences —mathematics, physics, chemistry, and astronomy—is so vital to the continuing progress of science, the Foundation has allocated more than a third of its scientific research project support to these disciplines. Although the NSF has increased its level of support so that its share of university-based research in the mathematical and physical sciences has risen substantially, this has been insufficient to offset the funding decrease from other Federal agencies that have shifted some of their support towards research more closely related to their statutory mission.

In the area of physics during fiscal year 1971, the NSF granted 290 awards totaling $31.1 million as compared to 245 awards for $28.1 million in the previous year. This support can be considered to fall into two major categories. One category, elementary particle and nuclear structure physics, involves major facilities and requires significantly higher support per scientist each year than does the other category, which includes such programs as atomic, molecular and plasma physics, and solid state and low temperature physics.

The elementary particle physics program is affected not only by the costs of facilities, but by their operational status as well. The new National Accelerator Laboratory (NAL) at Batavia, Ill., built with Atomic Energy Commission funds, is becoming operational, and user groups are now turning to the Foundation to support the necessarily larger-scale research projects to be undertaken at NAL. There is also an increased demand for the use of the NSF-supported Cornell Electron Synchrotron. The strong demand for use of the Cornell accelerator arises both from its unique capability to provide high-duty-cycle, high-energy electron beams, and because of the phase-out of other accelerators. In nuclear physics, several new directions of research are emerging. Among the research topics of special interest are the microstructure of the nucleus, possible new super-heavy elements, and the range of new isotopes around stable elements of very high mass.

Because of the high productivity of solid state and low temperature physics, research is being supported on a wide front. In particular, there is a continuing interest in the prospect of wide technological use of low temperature physics phenomena such as superconductivity and superfluidity.

From a scientific point of view, physics is at a most promising point in its history. Over the longer range, it can be expected that new and significant developments will take place in studies of gravitational radiation, ultra-high density matter, cryogenics, and plasma physics.

The NSF has in the past been providing about a quarter of the annual Federal support of chemistry research projects at universities. As in the case of physics, the increased mission orientation and decreased funding by those agencies other than NSF supporting fundamental chemistry research has increased the fraction of the scientific research community looking to NSF for support. During fiscal year 1971, 488 awards in the amount of $18.8 million were provided for research project support in chemistry. This represents an increase of 39 awards and an increase of $1.4 million over the preceding year.

Although chemistry has undergone development in experiment and theory over many years, many fundamental questions remain. Despite substantial progress, we are unable to predict, in general, which atomic or molecular arrangement will produce a desired property. Also lacking is the ability to predict the optimum sequence of reactions to produce a desired molecule. A third fundamental problem of chemistry concerns the rate of chemical reactions. Of major importance to our understanding of chemical reactions are the mechanisms by which catalysts influence the rate of reaction without being permanently changed themselves.

There are many new initiatives in chemistry related to the fundamental problems of chemical structures and reaction sequences and rates alluded to above. Research is also under way on important new classes of substances such as liquid crystals and room-temperature superconductors. Subfields such as surface chemistry and electrochemistry are becoming increasingly important. In electrochemistry, ion-specific electrodes are receiving a great deal of attention. Ten years ago, electrodes which would respond to a particular ion were virtually unknown. Today, electrodes are commercially available for at least 20 ions, and some electrodes have been developed which are sensitive to organic molecules.

Instrumentation plays a central role in chemical research regardless of the problem area under investigation. Adequate instrumentation is a necessity for chemical research, and despite university contributions there remains a continuing need and backlog to be met by NSF, which is the only explicit Federal source of funds for chemistry department instrumentation.

The Foundation is now the most important supporter of ground-based astronomy, furnishing about 70 percent of the total Federal support in this area when research project support, facility and equipment programs, and the four national astronomy centers are considered. During fiscal year 1971, 135 awards in the amount of $6.4 million were awarded for scientific research project support at universities. This was an increase of 27 awards and $.6 million over the previous year. Total obligations for all astronomical observatories increased $6.0 million to a total of $21.7 million in fiscal year 1971.

Astronomical research is characterized by observation instead of experimentation, and its subject matter involves extremes of density, temperature, space, and time which are far greater than those dealt with in the other physical sciences. Among the recent advances in this discipline are the detection of additional molecules in interstellar space and high-resolution spectroscopic studies of a quasi-stellar object receding at more than 80 percent of the speed of light, which reveal fundamental new information about the history of the universe.

There has been a rapid growth in recent years in the mathematical sciences due to the increased numbers of highly qualified mathematicians, the expanding role of mathematics in society at large, and the remarkable changes in teaching of elementary mathematics. The power of recent research is evidenced by the solution of numerous famous problems of mathematics which had defied solution for many years. Also, mathematical methods are increasingly penetrating the biological and social sciences. In large measure, this has been made possible by the computer, itself the offspring of advanced mathematics, the other physical sciences, and their related technologies.

The NSF is now the largest single source of funds for academic basic research in mathematics and, in fact, Foundation funding is slightly more than half of the total available from all sources.

The level of Foundation awards has remained essentially constant over the past 5 years (535 awards in the amount of $12.9 million in fiscal year 1971) so that its position of major support is the result of declines from other sources of support. Despite these factors, the mathematical sciences in the United States are now in a period of scientific growth, utility, and appeal.

CHEMISTRY

Metastable Species

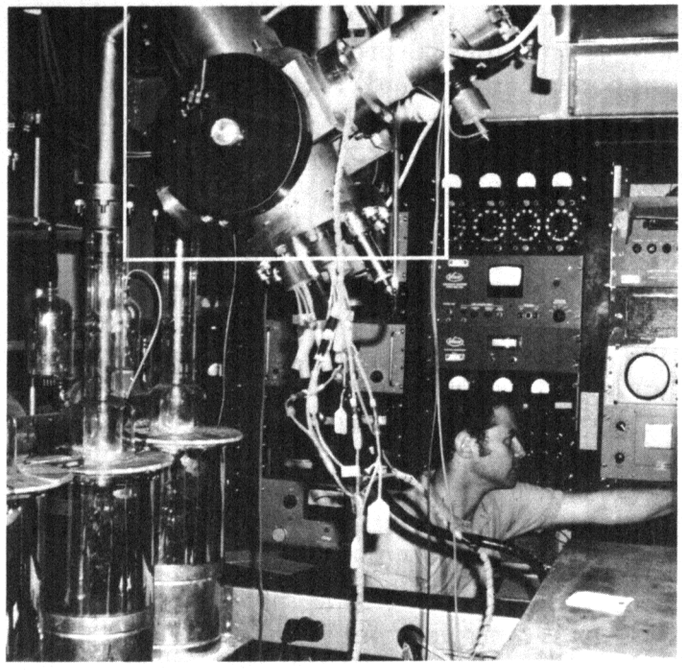
The transformation of energy from one form to another that usually accompanies chemical reactions is often as important as the change in the chemical nature of

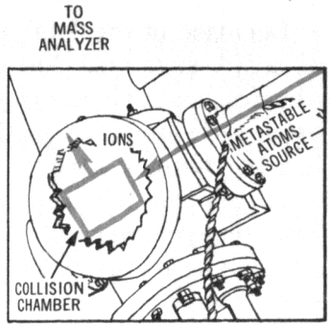
the materials involved. For instance, the products of oxidizing certain mixtures of hydrocarbons are relatively unimportant—except insofar as they may contribute to pollution—compared to the fact that the energy produced in the reaction makes the internal combustion engine possible. In the future, much more complicated chemical reactions, now known to occur in shock waves, flames, and certain types of electrical discharges, may become important as they apply to new techniques for the generation of electrical power or totally new forms of portable engines. In the meantime, detailed knowledge about energy transfer is relevant to understanding and controlling the rates and products of chemical reactions.

As energy is put into a chemical system, atoms and molecules temporarily absorb energy which they then generally lose by emitting light or by colliding with other particles —which is often the driving mechanism behind a chemical reaction. However, there are certain of these temporary levels of energy at which such radiation is relatively unlikely. An atom or molecule which stays in such an energy state for any appreciable length of time is called metastable.

Metastable species are important in reactions between gases because they may remain in an excited state long enough to make a number of collisions and therefore be more likely to become involved in a chemical reaction.

Studies of the properties of metastable atoms and molecules, primarily in electrical discharges, have been hindered by the fact that this is an extraordinarily complex environment. It is a mixture of different kinds of particles, in which a number of different reactions may be occurring simultaneously and consecutively, and in which the energy distribution among the particles is subject to wide variation.





Beam of excited, metastable atoms, generated by bombarding gas with electrons of controlled energy, reacts with atoms and molecules of low pressure gas in collision chamber. The resulting ions and their energies can then be identified and analyzed.

Earle Muschlitz, Jr. at the University of Florida has overcome many of the difficulties of the electrical discharge environment by using a molecular beam technique to study energy transfer and reactions involving metastable species. Dr. Muschlitz produces a molecular beam of helium, part of which he excites to metastable states by bombarding it with electrons of controlled energy. This impact produces two different metastable states which differ only slightly in energy but which have different magnetic properties. By using a magnetic field which is not uniform, Dr. Muschlitz is able to deflect a selected state out of the beam and determine how the proportions of the two are determined by the energy of the electrons producing them. He is then able to pass the beam through a gas at low pressure and, because he knows its composition, determine the relative likelihood of interactions of the two metastable states with the molecules of the gas.

In principle, this experiment is relatively simple, yet it provides answers to some rather subtle questions, some of long standing. Furthermore, in some instances the results have been contrary to what had been predicted theoretically and have therefore provided a basis for a revision of some thoroughly basic theories about chemical reactions.

These studies both provide very basic insights into the nature of a class of chemical reactions and move ever closer to possible practical preparative techniques.

Catalysts

Many important industrial-chemical processes, especially those dealing with refining crude petroleum into fuel, lubricants, and other useful chemicals, are made economically feasible by the use of catalytic materials. A catalyst is a material which "helps out" in a chemical reaction without itself being consumed in the process. In the field of petroleum chemistry, two general forms of catalysts have been known. The first and most commonly used form is the solid or heterogeneous catalyst, often comprised of tiny metallic particles bound to clays and other insoluble supports. The other

form, not as commonly used, consists of soluble complexes of metals belonging to what chemists call the transition groups, which include platinum, rhodium, and palladium.

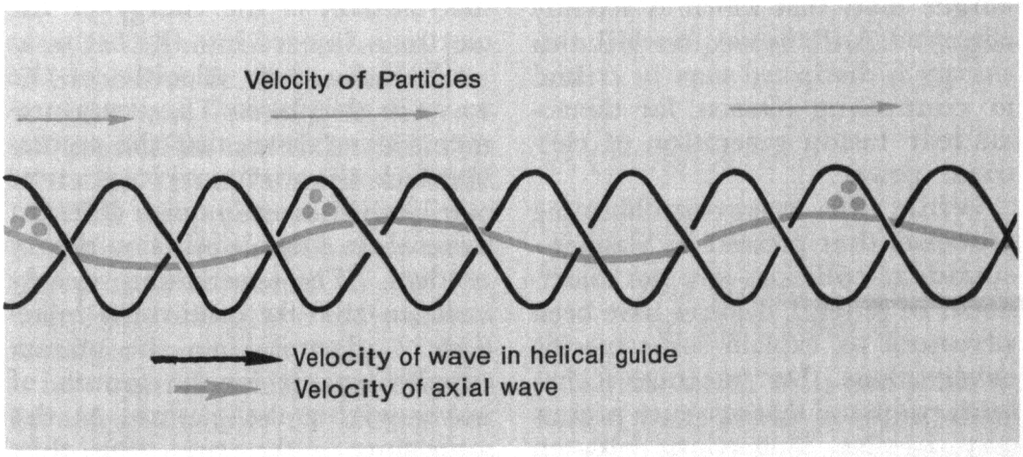
The insoluble catalysts have been the subject of intensive research during the past 3 decades, but their exact structures and the mechanisms by which they work are still largely unknown. On the other hand, the more recently discovered soluble catalysts have better understood mechanisms which chemists can alter minutely to do highly specific tasks and minimize the production of undesired byproducts.

Unfortunately, the use of the soluble catalysts is accompanied by a number of problems. In the first place, they are not particularly durable catalysts. Furthermore, industry is hesitant to employ these expensive noble metals in solution because of the difficulties of recovering the catalysts from the product in which they are dissolved. Finally, there are a number of important reactions which these soluble materials do not catalyze and which the insoluble catalysts do.

The best aspects of both systems have been combined in recent experiments by James Collman at Stanford University. Soluble compounds consisting of several of the transition metal atoms joined in a cluster by metal-to-metal bonds have been chemically fastened to porous, insoluble plastic supports. When Dr. Collman activates these clusters by removing carbon monoxide groups, he obtains an insoluble material with the same catalytic specificity as the soluble transition metal catalyst.

For example, a catalyst composed of tetrameric (four-atom) rhodium units will catalyze the hydrogenation of benzene and other similar compounds—converting them into useful intermediates for chemical synthesis—at room temperature and atmospheric pressure, rather than the high temperatures and pressures hitherto required. His preliminary experiments suggest that the rhodium clusters remain intact and can be recovered unchanged. The exact nature of this new class of catalysts is not yet fully resolved, but Dr. Collman's experiments show the possibility of preparing specific well-defined insoluble catalysts which can be "tailored" like soluble catalysts to perform desired reactions efficiently.

This system also offers an opportunity for chemists to study the detailed mechanisms by which the much used but poorly understood insoluble catalysts perform their tasks. The disadvantages associated with the use of soluble catalysts can be circumvented without losing many of their advantages by using this new type of system.



Ions of heavy elements are introduced in front of slow-moving wave crest in axis of double-helical wave guide. "Surfing" effect causes particles first to slip to rear of wave, focusing them. Wave accelerates particles until they are again in front of wave crest, and accelerator section terminates. Pitch of helix determines velocity of axial accelerating wave—successive sections have lower pitches and faster axial waves.

PHYSICS

High Speed Particle Control

Most high energy particle accelerators—linacs, cyclotrons, synchrocyclotrons—operate successfully by application of a "phase stability" principle, somewhat equivalent to "particle surfing." The accelerated particles ride on the forward side of the wave, near the crest. If a particle is moving too slowly, it slips backwards towards the crest and is speeded up; if it is moving too fast, it moves down towards the trough and slows down. The particles, like the surfer, are forced back toward their original position on the wave, and the system is said to be stable. The velocity of the wave, of course, must be continuously increased to match that of the accelerating particles.

When these phase stability conditions apply, the particles unavoidably are able to slide to and fro parallel to the wave crest. For a surfer, this is of little importance, but in an accelerator it means that the diameter of the beam grows with time and quickly would become too large and diffuse to be useful if other lens-like devices were not added to keep the beam focused.

If the particles were forced to ride on the rear of the wave crest, the beam would automatically be focused. However, in this position, the particles would fall out of phase with the wave and not be accelerated properly. If it were possible to force the group of particles being accelerated to periodically alternate their position from the front to the rear of the wave crest, both acceleration and focusing could be achieved without the need for additional lenses.

Thomas Tombrello at the California Institute of Technology has proposed a method for accomplishing this automatic focusing and phase stability at the same time. Dr. Tombrello proposes that particles to be accelerated should be introduced into a section of the accelerator just in front of a wave moving at a fixed speed, slightly higher than that of the particles. The group of particles would "slip" with respect to the crest until it was on the wave's rear side, thereby being stable with respect to focusing. However, the motion of the wave would be causing the particles to accelerate, and if the relative velocity of wave and particles were correctly chosen, the particle velocity would equal and finally exceed that of the wave. Thus, the group of particles would automatically advance again to the forward side of the wave. At this point, the acceleration would be terminated so that the particles would not move further into the trough of the wave and be slowed down. In this "slingshot" operation, the particle group is focused and accelerated. Further acceleration may be achieved by introducing the particles into a series of further "slingshot" sections with correspondingly higher wave velocities.

This effect may be very useful in the acceleration of very heavy elements like uranium for the production of new transuranic elements. The difficulty of using a linear accelerator for this purpose has been that the accelerating waves have been too fast for those of the slow-moving low-energy uranium ion—an effect similar to stepping onto a too-fast moving platform.

At the same time, it is known that a wave traveling along a helical conductor, or wave guide, can produce a field velocity along the axis of the helix, or an axial velocity, equal to about 2 percent of the speed of light. It has recently been found that if a second helix, wound the opposite way, is placed concentrically with the first, an axial wave velocity of less than 1 percent of the speed of light can be produced.

Combining the double-helical wave guide and the "slingshot" effect would allow physicists to start off with a "slowed-down" accelerating wave which is more nearly the speed even of the low-energy heavy uranium ions. A succession of accelerating sections of ever-faster waves can then be used to achieve the desired acceleration.

Equilibrium Processes in Plasmas

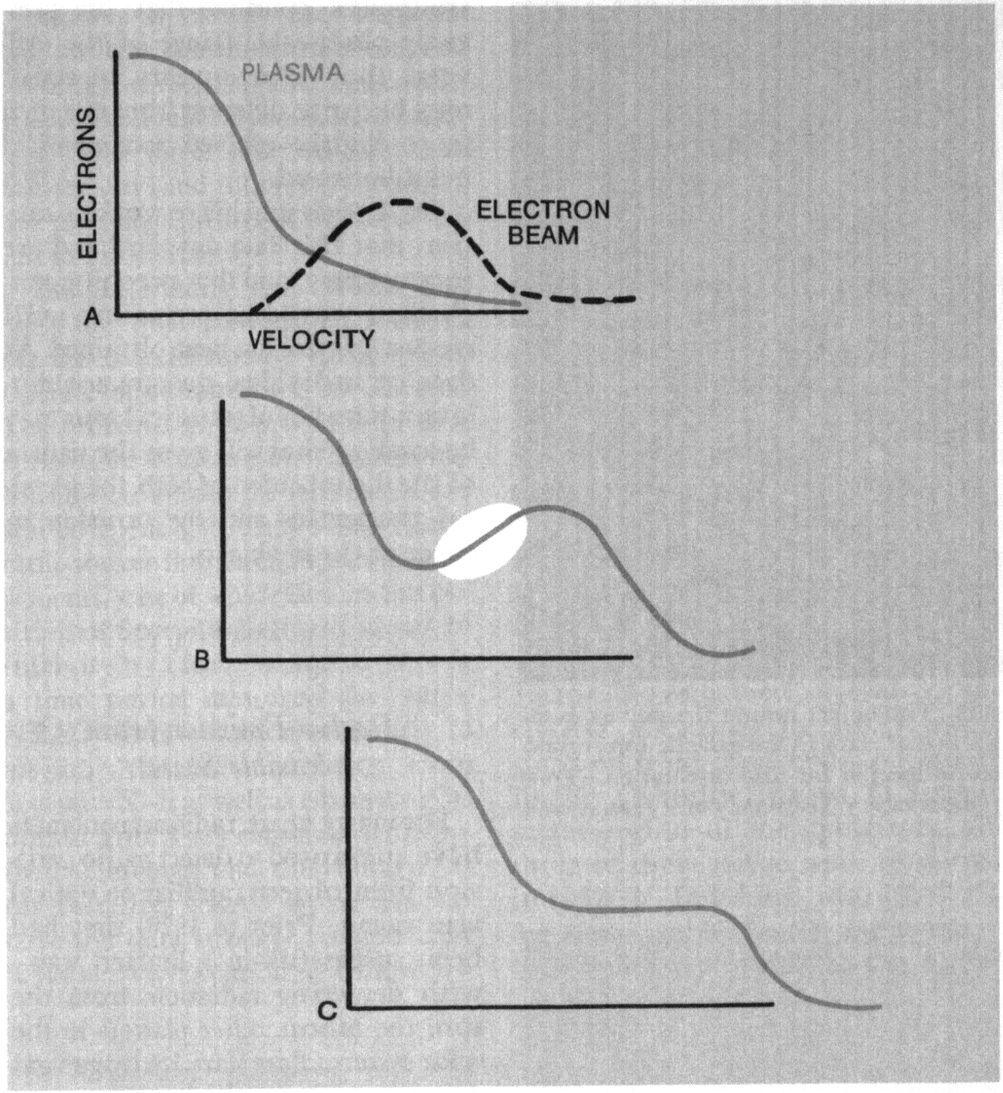
One of the fundamental physical facts of the universe is that a system in which energy is unevenly distributed will eventually achieve thermodynamic equilibrium (the even distribution of energy throughout the system). In nearly all physical systems, this thermodynamic equilibrium is reached by a process of simple collisions between the particles of the system which distribute the energy evenly. This process is well understood and quite predictable.

A plasma—a "gas" of ions and electrons—however, is an exception. Collisions between the ions and electrons in a plasma are rare, and do not explain the rate at which equilibrium is reached: The equilibration time predicted from collision theory may be hundreds of times longer than that which is actually observed. And the way in which this energy is dissipated may be crucial to controlling plasmas for themonuclear fusion generation of electrical power.

While the energy-equilibrating processes that proceed in plasmas—outside of collisions—are not understood in general, theories have been advanced to explain some specific observations. For instance, it has been proposed that one such process may involve interactions between the individual particles of a plasma and the wave motions set up by the oscillations of the particles as a whole. Kenneth Gentle and his colleagues at the University of Texas at Austin have confirmed the existence of several such types of interactions, and have shown that they may, indeed, lead a system of initial energy unbalance to equilibrium.

Dr. Gentle's first experiment demonstrated the existence of an effect termed "nonlinear Landau damping." Many waves may propagate through a plasma without apparent absorption. A system in which such waves were excited would not, because of the waves alone, relax to a uniform equilibrium. Theoretically, however, it was predicted that an interaction between different waves propagated through the plasma at the same time would lead to a nonlinear interference between the waves and the subsequent "damping" would result in wave energy going into heating the particles. In a set of experiments using pairs of waves propagated through the plasma simultaneously, Dr. Gentle and his co-workers demonstrated that the interaction was completely in accord with theoretical predictions.

One of the simplest and most basic forms of instability in a plasma arises from the injection of a beam of electrons into a plasma which was initially at equilibrium, thereby modifying the distribution of the electrons' velocities. Dr. Gentle's group has been able to measure, in a second experiment, the statistical distribution of the energy of the electrons injected into the beam, as well as the phase velocities of the waves in the plasma. These measurements have shown that the process by which the plasma arrives at a new equilibrium is again quite different from what a simple collision theory predicts. The experiments clearly indicate that the continuing injection of electrons into the plasma supplies energy for the growth of waves within the plasma. At the same time, as the waves grow, they begin to interact with the particles and cause them to diffuse to a lower velocity. This effect produces, both mathematically and in the physical system, a new equilibrium distribu-



Electron beam injected into stable plasma (A) adds an unstable "bump" to high-velocity region of graph of electron velocity distribution (B). Plasma waves with phase velocities corresponding to electrons in the shaded portion grow, interact in turn with particles in the plasma and push them into lower-energy regions, producing new equilibrium (C).

tion. In this second experiment, just as in the first, Dr. Gentle and his coworkers have learned that theoretical predictions match the behavior of the real system in complete detail.

While the problem of energy distribution in the equilibrium-forming process in plasmas is not yet completely solved, it is fully understood for some cases. The problem is now open to careful experimental investigation, since the theory has been shown, so far at least, to live up to expectations. Physicists reasonably expect that these processes will be virtually completely understood within a few years, thereby providing a stronger basis for the understanding of plasma physics in general.

ASTRONOMY

Kitt Peak National Observatory

The Optical Edge of the Universe

In 1969, Derek Wills and John G. Bolton made precise position measurements of a radio source known as 4C 05.34. Using the Parkes, Australia, 210-foot radio telescope, Drs. Wills and Bolton tentatively identified this source as a quasistellar object, or quasar. The radio position was subsequently confirmed as being identical with that of a very faint blue, star-like image, and identified as having the largest red shift yet observed. The red shift phenomenon occurs when an object is receding from the viewer, apparently stretching out the wavelength of the light by which it is seen. This stretching-out effect causes the light to appear redder (hence, the name) and the more rapid the recession, the redder the light. Using the 84-inch reflector at Kitt Peak, Dr. Wills and C. Roger Lynds made image tube spectrograms to obtain preliminary measures of the amount of the red shift, which indicated that it corresponds to a relative velocity in excess of 80 percent of the speed of light. (See NSF 20th Annual Report, p. 19.)

During 1971, Dr. Lynds continued his spectrographic studies of 4C 05.34 using new techniques with the image tube (an electronic device which multiplies the light received from a very faint object). He obtained observational material with unprecedentedly high spectral resolution and discrimination against contaminating sky light, revealing complex systems of absorption lines. Measurements and analysis of 93 of these lines have led astronomers to conclude that the absorption lines are caused by several gas clouds located along the line of sight between earth and the quasar. Because the red shift values derived for the absorption lines are themselves high, it is apparent that the gas clouds are at great distances, although not receding as rapidly as the original source. Furthermore, the absorption line profiles are unresolved, and indicate that the velocity dispersion (variations in velocity around some average value) along the line of sight of the gas in these discrete clouds is relatively small, signifying that there is little internal turbulence.

Dr. Lynds and others at Kitt Peak also studied the absorption line systems in a number of spectra of other quasars having large red shifts. The

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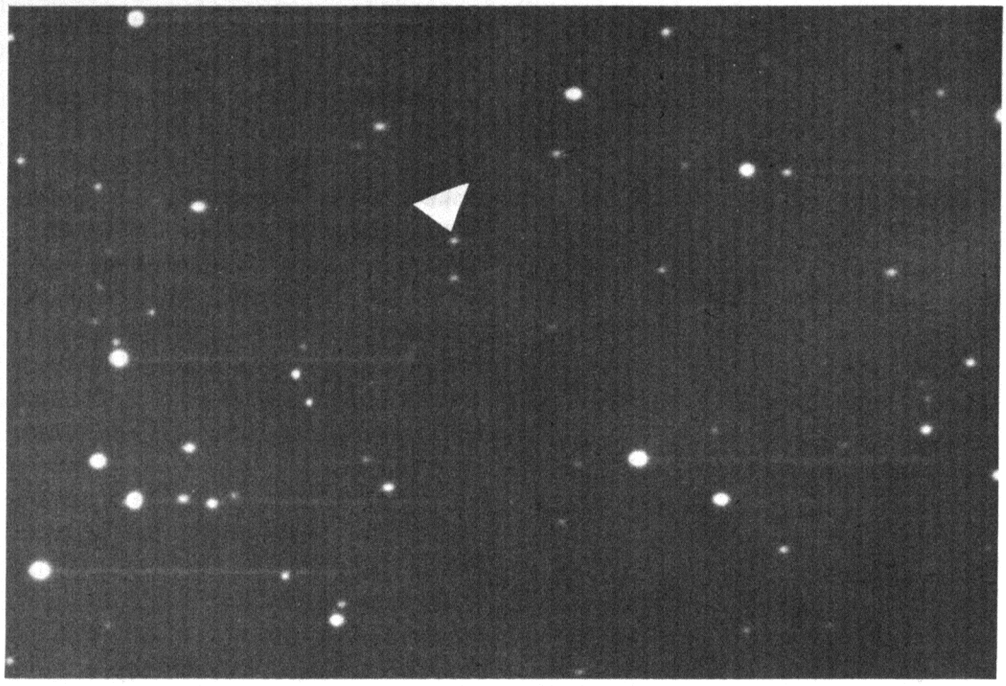
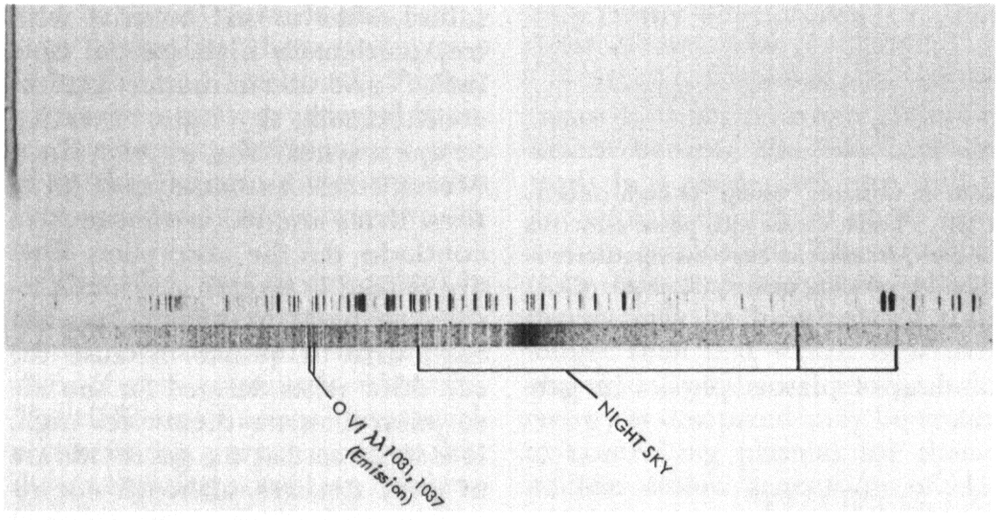


Quasi-stellar source with largest measured redshift. The object nearest the pointer is the 18th magnitude quasar 4C 05.34; all other images are of stars in the galactic foreground, with the brighter ones showing trails from telescope motion for field orientation. (From plate taken with 107-inch reflector of McDonald Observatory, University of Texas, Austin, by Dr. D. Wills.)



A 5Å resolution image tube spectrogram of the most distant optical source 4C 05.34 taken by C. R. Lynds. The redshift measured from the position of the emission lines (dark on this negative illustration) is $Z = 2.877$, which means the object may be receding at more than 80 percent of the velocity of light. (Photo KPNO)

general picture emerging is one of very luminous distant objects, which are at a relatively early stage of evolution with respect to the age of the universe, representing a state of matter and an association with gas that is not characteristic of similar volumes near our own galaxy. (The quasars being studied are said to be at an early stage of evolution because they are so far from earth that the light now being received from them left them when the universe was a tenth of its present age.) Astronomers conclude that the presently observable fringe of the universe that these quasars represent may be quite different from our own more highly evolved astronomical neighborhood.

Dr. Lynds and his co-workers caution that the data now on hand are fragmentary, and that sweeping conclusions would be premature until more evidence has been obtained. As data on individual quasars accumulate, a number of statistical tests may be applied that will assess the nature of the distribution of both the physical properties and the position in space of these objects.

National Radio Astronomy Observatory

Radio Emission from Visible Stars

For many years, radio astronomers have attempted to detect radio emission from objects familiar to optical astronomy. Prior to 1970, they had been successful—in a limited way—with detecting radiation from the sun, the moon, other planets in the solar system, flare stars, hydrogen gas clouds, remnants of supernovae, quasars, and a few galaxies. During the past year R. M. Hjellming and Cameron Wade of the National Radio Astronomy Observatory (NRAO) have succeeded in conclusively detecting radio emission from three new classes of objects: a normal red supergiant star; a strong X-ray emitting star; and a group of ordinary novae.

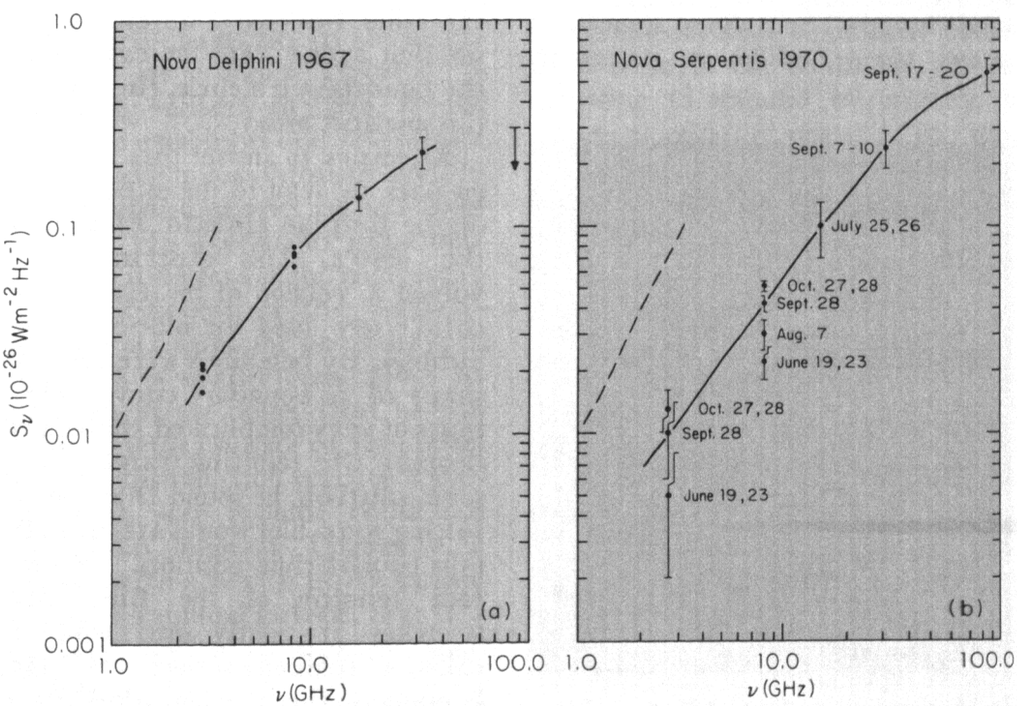
Within a few days after the installation of a new receiver system on the NRAO interferometer, Drs. Hjellming and Wade detected radiation at a wavelength of 11 centimeters from the red supergiant star Antares. Although one or two NRAO observers had suspected the presence of radio emission from supergiants previously, this was the first positive evidence for detection, opening up the field of stellar astrophysics to radio astronomy.

Antares is visually the brightest star in the constellation Scorpius. With better receivers and larger telescopes, it should be possible to measure radio waves from smaller and fainter stars and ultimately to measure the temperatures of the individual stellar surfaces.

Drs. Hjellming and Wade also used the dual wavelength receiver on the interferometer, designed to operate simultaneously at 3.7 and 11.1 centimeters, to provide the first conclusive evidence of variable radio emission from the intense X-ray star Scorpius X–1. They resolved the radio source into three separate components, one of which lies in the position of Scorpius X–1 and varies in intensity by a factor of up to 50 over a time period measured in hours. NRAO observers are continuing to monitor the radio emission from Scorpius X–1, as well as observing its optical and X-ray emission with optical telescopes and the Uhuru X-ray satellite. NRAO observers believe the data strongly suggest that X-ray activity occurs first, followed a few days later by optical activity and, after a few more days, by radio variations. By thorough analysis of data from all three sources, astronomers will be able to determine the radius of the active region.

Because X-ray detectors still have relatively poor resolution, it is often difficult to "find" X-ray stars optically, particularly in crowded regions of the sky. However, now that astronomers know that these peculiar variable sources can be detected by radio emission as well, they can measure their positions sufficiently accurately to make positive optical identification—which will help to solve the enigma of the nature of these X-ray sources.

Drs. Hjellming and Wade and Victor Herrero used several of the NRAO telescopes to study radio emission from three ordinary novae in the 3.5 millimeter to 11.1-centimeter region of the spectrum. All three of these novae were observed in 1967 (N. Delphini) and 1970 (N. Serpentis and N. Scuti) and were, at their brightest, visible to the naked eye. Astronomers suspect that their radio emission is probably of thermal origin. It is optically "thick," or opaque, in the initial stages of the explosion and becomes thin as the nova expands with time. Optically, N. Delphini was one of the slowest, yet most spectacular novae on record. It experienced at least six distinct shell ejections or explosions. Correlations between the optical and radio variations in novae will provide clues that will lead to more complete understanding of how these star explosions occur.



Spectral data for Nova Delphini 1967 and Nova Serpentis 1970. Because of the rapid radio brightening of Nova Serpentis 1970, each data point for this object is accompanied by the date of measurement. Dashed lines, spectral slope expected for an optically thick thermal source with a uniform emission measure. (Photo NRAO)

University Research

New Windows on a Chemical Universe

Astronomers have been tremendously stimulated in recent years by both the extension of the observational spectrum available to them and the development of a field which might be called "astro-chemistry."

University research in astronomy has used the surface of the earth, balloons, rockets, and even satellites as platforms from which to collect and study electromagnetic radiation in the radio, infrared, ultraviolet, X-ray, and gamma ray portions of the spectrum. There are recent indications that the observable spectrum has been extended to include the measurement of gravitational radiation as well (see NSF 19th Annual Report, p. 18). It is now becoming possible to correlate observations made in different regions of the spectrum by entirely different groups. For example, two recently discovered galaxies, Maffei I and II, just barely visible on the photographic plates in the visual light portion of the spectrum, show up more clearly when photographed by infrared light. These two galaxies are of special interest because they are very near our own galaxy by astronomical standards (approximately 6 million light-years away). Although these two galaxies are in our local

group and are of respectable size, they have eluded study until just a few months ago, because they lie in such a direction that their light must pass through the greater thickness of our own galaxy before it reaches us. Our galaxy contains a great deal of interstellar dust, which scatters blue light more than red. Consequently, most of the light that "survives" to reach the earth appears reddened, much as the light from the setting sun is reddened by dust in the earth's atmosphere. Infrared photographs had hinted previously that these two galaxies were present. These more recent plates have proved conclusively that these galaxies are part of our local group. Furthermore, measurements of these galaxies in the infrared now show that they are approximately normal galaxies. Astronomers are now looking toward further research in the visible and radio wavelengths to provide more information; one of the Maffei galaxies is a known radio source.

In the last few years, the number of different molecules proven to exist in interstellar space in our galaxy has grown phenomenally. These molecules have been detected by radio astronomy groups both at the National Radio Astronomy Observatory and at various university installations. For the first time, however, simple molecules have been detected in galaxies outside our own. L. N. Weliachew, a visiting astronomer at the California Institute of Technology, has discovered such molecules in at least two galaxies.

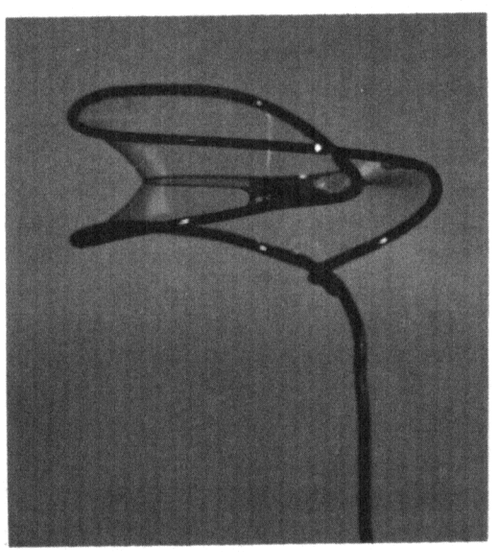
The question as to whether there are even more complicated molecules elsewhere in the universe may be soon answered. There is no reason, in principle, that organic and other molecules in other galaxies cannot be detected. This, of course, raises questions bearing on the possibility of extraterrestrial and extragalactic life which can perhaps be answered by the techniques of radio and other types of astronomy. The discovery of these molecules has now prompted much research in physics and chemistry to find out what processes take place in interstellar space that can produce and preserve these molecules for long periods of time.

Eight new molecules were observed between January and June of 1971—the most recent being methyl alcohol, methyl cyanide, and silicon oxide. There seems to be almost no end to the types of molecules that can be discovered. The identification of the molecules themselves is now a real part of the problem. As soon as other scientists can find and identify the lines of various molecules accurately in the laboratory, radio astronomers can search for the spectra of these molecules in interstellar space.

MATHEMATICS

Branch Points of Minimal Surfaces

When a mathematician says, "Among all one-dimensional configurations or paths, with the same zero-dimensional boundary, the straight line path has a unique minimal length," he is doing something more than finding an extremely complex way of saying, "The shortest distance between two points is a straight line."



Surface tension stretches fluid soap film across wire-frame boundary curve into a "minimal surface." Same boundary curve may give rise to several different surfaces, each behaving like a minimal surface.

The advantage of the mathematician's roundabout approach is that it is phrased entirely in terms that have counterparts in higher dimensions. For instance, the basic two-dimensional configuration, a surface, has a boundary which is a one-dimensional curve. (In each case, the boundary has one less dimension than the configuration it bounds.)

Just as there are many paths that may join two points—and only one, the straight one, is the shortest—many surfaces may have the same boundary curve. For instance, a rubber ball is made up of two hemispheres, each of which has a circle for a boundary. The same circle may be a boundary for a globular surface like a fish bowl, a bottle, a shallow bowl, or a disc.

But not all boundaries are as simple as a circle, or surfaces as simple as half a rubber ball. Mathematicians have for some time been working on the next higher dimension of the "shortest path" question and asking, "Of all surfaces which have the same boundary, which has the smallest area?" (For the case where the boundary is a circle, the disc has the smallest area.)

Attempts to answer this question go back at least to the experiments of the Belgian physicist Plateau in the 1840's. This experiment involved a version of the traditional child's toy used for blowing soap bubbles. By bending a wire into the shape of a boundary curve, sometimes of very complicated shape, and dipping the resulting frame into a soap solution, he found that the resulting soap film would attain a certain equilibrium position. The surface tension of the fluid film stretches it tightly into what is called a "minimal surface." Strangely enough, the same boundary curve —or frame—may give rise to several different surfaces, each of which behaves as though it were a minimal surface.

In the early 1930's, the first formal mathematical proof was established, showing that a large class of boundary curves do indeed have minimal surfaces associated with them. Since there is an infinite number of possible boundary curves, it would be impossible to examine every curve and surface individually. The actual formulation of the minimal surface problem involves a set of complicated mathematical functions.

Robert Osserman at Stanford University has been trying to find out whether there are minimal surfaces which possess a type of deficiency called a "branch point." A branch point—a difficult phenomenon to visualize—involves a series of rays stretching out from a point along which the surface intersects itself, and in the vicinity of which the surface understandably becomes quite complex. It was not known whether a minimal surface was necessarily free of such points.

Dr. Osserman has recently shown that this is indeed the case. His proof consists of two basic steps. First, he identifies mathematically the nature of a surface in the neighborhood of a branch point on a minimal surface. In the formal proof, he establishes that the surface would have to pass through itself in a well-defined number of self-intersections. His second and more difficult step involves a slight mathematical modification of the surface—without changing the boundary—to one with a smaller area. Since he assumed at the outset that he was working with a surface of minimum area, a contradiction results: a surface with such a point could not have been minimal. Therefore, a surface with a branch point cannot also be a minimal surface, that is, a minimal surface is free of such points.

Dr. Osserman's proof involved some delicate geometric arguments which he supported with careful analysis. Since he resolved this question in 1970, still another proof has been discovered which reinforces and extends his fundamental result.

BIOLOGICAL AND MEDICAL SCIENCES

Foundation programs in the life sciences are being challenged by the unusual opportunities for the development of new knowledge and changes in the organization of research activity. Through 1,369 awards totaling $43.4 million in fiscal year 1971, new information is being developed about the molecules that make up biological systems and the way in which they organize themselves into functional systems, giving rise to the tremendous range of anatomical forms which have led some observers to characterize biology as the study of diversity. The scope of problems which can now be addressed in quantitative terms rather than in an exploratory or qualitative way has grown far beyond the Foundation's capacity to pursue all of these problems in a vigorous way.

In addition to the challenge of much more difficult choices in priorities, there is the challenge of attempting to respond effectively to moves to organize research in substantial team efforts. The integrated research programs of the International Biological Program (see p. 38 for discussion of research results) are a prime example of the development of such collaborative research teams now attempting to address problems of a magnitude that could not be undertaken by a few investigators and supporting personnel. Experience to date has demonstrated that integrated team research in biology is quite feasible when proper attention is paid to the new managerial problems presented by this approach. It is our hope that it will be possible to demonstrate both a new capacity for dealing with complex problems and the ability to make progress more rapidly and economically.

The Foundation's program of biological and medical sciences is so diverse that it is impossible to characterize it briefly. The twin themes of recognition and regulation, however, run through essentially the full range of biological research.

At the molecular level, the fidelity with which genetic information is copied and passed on to new generations depends on chemical recognition which can be largely identified with bonding between specific pairs of molecules. Research supported by NSF is adding to the evidence that chemical "recognition" between component molecules also determines the organization of viruses, membranes, and other complex biological structures.

The molecular basis of gene expression and its regulation continue to attract substantial NSF support. Precisely how are the plans, which are stored in a finite number of DNA molecules in a fertilized ovum, translated into the complex structures found in an adult organism? If, as now seems clear, the cells in different parts of an individual may have identical complements of this genetic information, why do they differ so greatly in form and function? One hypothesis developed to explain this was that there is a class of regulator genes which has the function of making repressors, each of which functions to prevent a structural gene from making its product. After a decade of research, such a repressor was isolated in purified form, and it was shown (see 17th NSF Annual Report, 1967, pp. 34–35) to exert its regulatory action by combining with the specific gene which it controls (regulation through chemical recognition). Although repressor genes and their products have been demonstrated only in bacterial and viral systems, higher organisms probably operate in a similar way. A major and as yet relatively undeveloped line of research will extend these same approaches to higher organisms and provide a better basis for dealing

with genetic diseases and abnormalities of development.

Recognition and regulation are, again, central themes in studies of immunity. How do organisms or cells recognize that bacteria, viruses, or other foreign substances are different, and initiate a complex of responses to dispose of them? What goes wrong with the regulation of this process when an organism begins to treat cells of some of its tissues as foreign, and an autoimmune disease develops? Although much progress has been made in understanding the molecular basis of the antigen-antibody reaction—again, chemical recognition of one molecule by another—much remains to be learned about the cellular basis of immunity.

The whole range of behavioral problems may be put in the same framework of recognition of particular sensory stimuli in a discriminating way, and the steps by which these sensory inputs are processed to regulate the behavior of an organism. In what cases can the regulatory processes be modified by learning, and in what cases are these processes fixed? For example, research on depth perception has shown that in some animal species this kind of visual discrimination must be learned, while in others it appears to be an innate response. The study of the ability of prior sensory experiences to modify behavior and the mechanisms by which this is accomplished is, of course, the study of learning. Such research is an area of increasing emphasis in the NSF life sciences program.

The chemical regulation of behavior has become a particularly lively area of research. Some studies deal with the behavior of very primitive organisms. One such case is the behavior of the slime molds. At one stage in its life, the mold consists of individual, motile cells. At the proper stage of development these individual cells "swarm," and as they meet each other, fuse to form a multicellular organism. It has been clear for some time that the motile cells must be signalling each other with a chemical attractant, and more recent research has shown that this attractant is cyclic adenosine monophosphate (cyclic AMP) (see 19th NSF Annual Report, pp. 37–38). This was particularly exciting because cyclic AMP has been known to play a role as a chemical messenger, or intracellular hormone, in several important processes in higher organisms, and more recently it has been shown to play a role in regulation of enzyme synthesis. These observations further emphasize the fact that, though the way in which a variety of options may be utilized gives rise to an almost infinite diversity of forms and specialized behavior, these are, to a considerable extent, variations upon common themes which pervade all of biology.

The Genetic Origins of Behavior

It has long been known that both genetic and nongenetic factors affect an individual's behavior, but attempts to separate the two are extremely difficult.

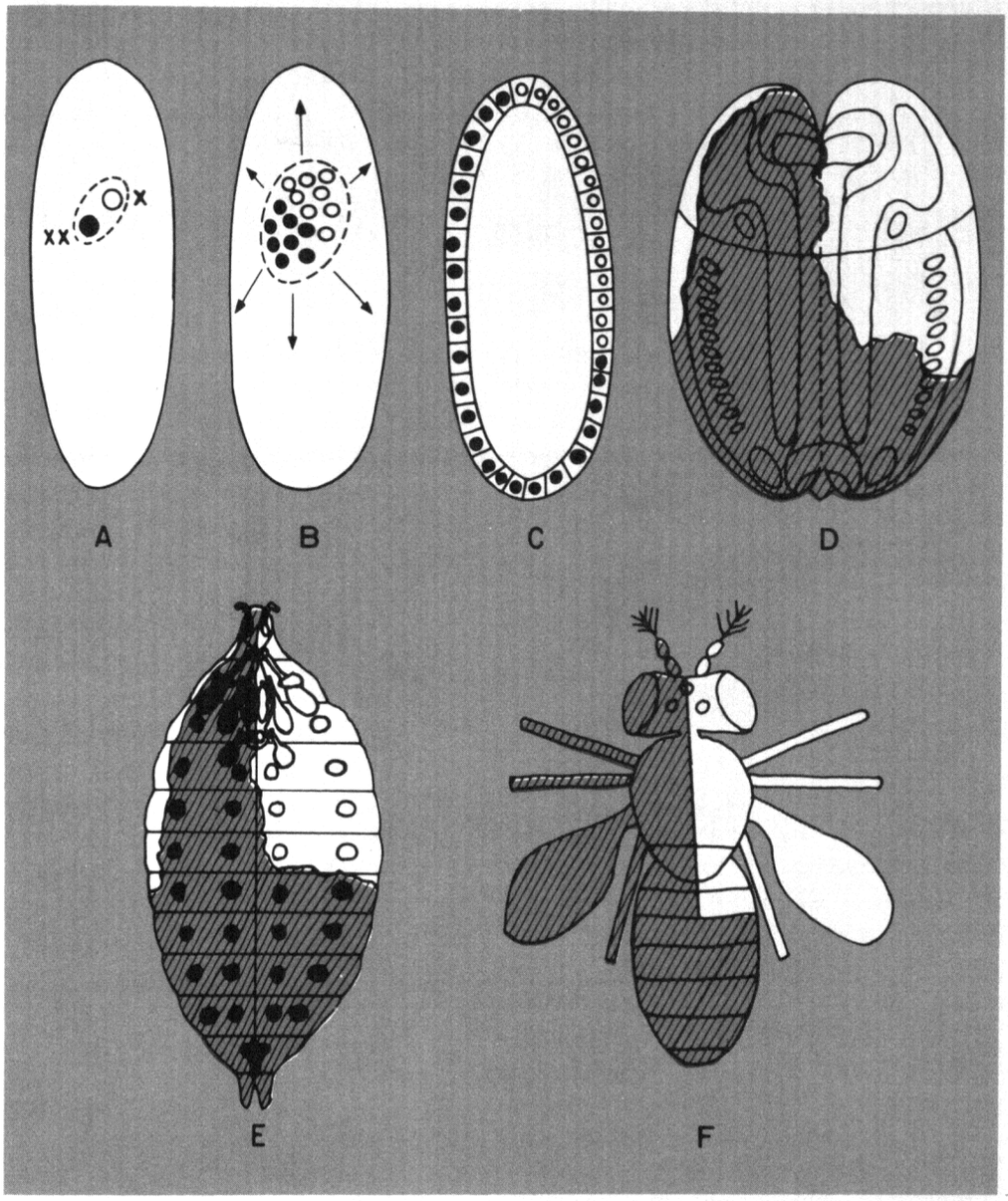
One particularly promising line of investigation of the genetic influence on behavior is being taken by a group at the California Institute of Technology. The group is under the direction of Seymour Benzer, a molecular biologist, who in the 1950's conceived a method for detailed mapping of genes using a virus.

Dr. Benzer has taken an approach to the study of behavior that is based more or less on classical genetics. He is trying to bridge the gap between geneticists, who have almost completely ignored the nervous system, and neurophysiologists, who have virtually neglected genetics. He chose to work with the fruit fly, *Drosophila melanogaster,* whose genetics was amply known from decades of study. His approach to investigating the genes and behavior is to start with a pure strain and see what changes in nervous system and behavior result from changing the genes one at a time.

Simple as it is compared to humans, *Drosophila* has a rich repertoire of behavior of genetic origin. From among those, Dr. Benzer's group decided to begin its work in a study of visual behavior. Normal flies exhibit a consistent response to light—they move towards it. At least two mutants that did not move towards light have been known for many years. Dr. Benzer's group isolated many more by adding a chemical to the sugar-water fed to male flies that greatly increases mutation rates. Dr. Benzer's group separates the mutants from the "normals" by an adaptation of the "countercurrent distribution" procedure used in biochemistry to separate molecules from a mixture.

After the flies are identified by their visual responses, they can be studied in more detail. The eye can actually be used as a photoelectric cell by means of an electroretinogram, a standard measurement used in diagnosing visual abnormalities in humans. To study visual mutants, the team puts electrodes on the eye and in the body itself. They then flash a short-duration light at the eye and measure the electrical response. The response of a normal eye follows a standard pattern, corresponding to the steps in the visual message towards the brain. An abnormal electrical response may give an indication of where a defect occurs in the visual sequence. The group has so far identified seven different genes that can undergo mutations that show up in both the electroretinogram and some aspect of behavior. For several of those mutants, they have also identified specific anatomical abnormalities in the visual system.

But a real question frequently exists as to where in the body the focus of the defect lies. If an eye of a fly with some visual defect is re-



Development of a Mosaic Fly—Fertilized egg (A) is female (XX), but one of the X chromosomes is unstable. In A, the unstable chromosome is lost during the first division so that one daughter nucleus is female (Black, XX) and the other male (White, X). The resulting male and female cells migrate during early stages of development (B, C), and tissues descending from them are either male (white) or female (shaded) during all successive stages of development (D, E) to produce the part-male, part-female adult gynandromorph or mosaic fly. (Diagram courtesy of Seymour Benzer, California Institute of Technology.)

placed with a normal eye, vision may be restored. Of course, transplanting an eye or a part of an eye in a fly is not practical surgically. But it is quite possible genetically.

The technique takes advantage of a rare strain of fly whose offspring are sometimes composites of male and female—a gynandromorph or mosaic fly. Such offspring can be part normal-female and part mutant-male—and the pattern is random, providing a range of combinations. It is easy to determine if a part is normal or mutant, because the male portions of the composite display masculine secondary sexual characteristics, and the female portions, female.

Dr. Benzer and Yoshiki Hotta on his research team used this in studying visual behavior. They tested 44 different normal/vision-mutant mosaics and made electroretinograms from both eyes in each, checking the results against those of a normal fly. In each case, if an eye was of the normal genotype, it behaved normally; if it was mutant, even if the rest of the head and body were normal, the eye was defective. For this particular mutant, the visual defect is clearly autonomous in the eye or in very closely associated tissues. While this is not a surprising finding, it could not be assumed without this kind of proof. But the neurological sites of other kinds of behavioral mutations are less obvious, and the technique will be an increasingly useful tool in localizing the site of the defect, at which point anatomical and physiological methods can be used to study it in greater detail.

While the male/female dividing line can be easily perceived on the outside of the fly's body, it does not necessarily follow the same pattern inside the fly. Moreover, the male/female internal tissues are essentially the same. What is needed is some way to distinguish between normal and mutant tissues, particularly in the brain.

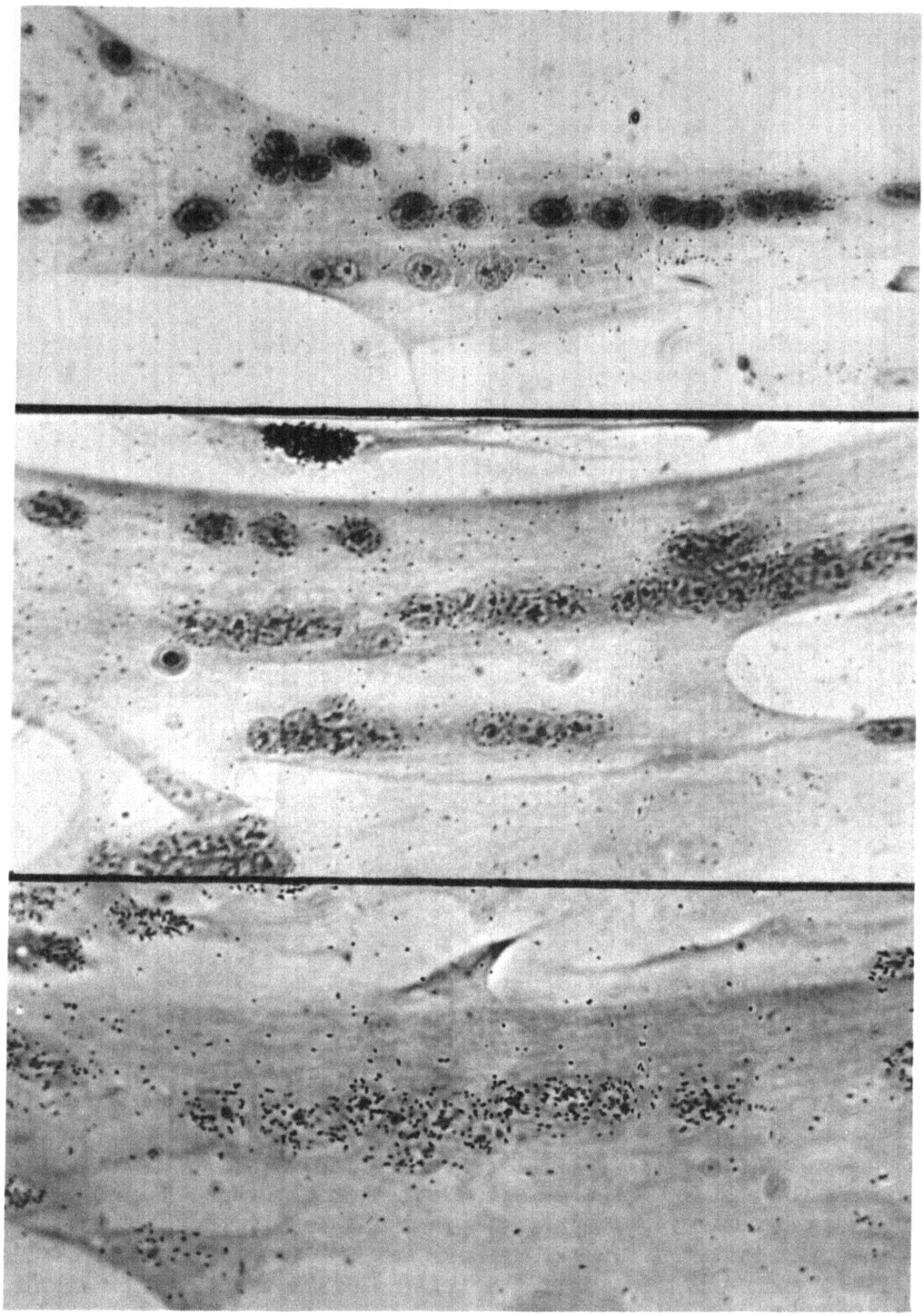
The team started off by looking for a gene on the X chromosome (the chromosome that determines sex and which undergoes an abnormal division to make a gynandromorph) that controls production of an enzyme that could be identified by staining. They could then take a section of brain, stain it, and the male part would turn one color and the female another.

They found an enzyme that exists normally in the brain and a corresponding mutant lacking it, but the controlling gene was on the third chromosome, not on the X. So they had first to "move" that gene to the X chromosome by irradiating chromosomes with X-rays and getting the proper broken section on the third chromosome to reattach to the X—a possible, but very tedious task.

Another way to distinguish between normal and mutant parts of the brain is to start with something known to be in the brain and then mutate the gene that controls it. Members of the group decided to look at an enzyme called acetylcholinesterase, in which the fly's brain is rich, and which is vitally linked to normal brain function. A fly lacking acetylcholinesterase would probably never survive, but it might be possible to find a mutant in which the enzyme would be temperature-sensitive. Below a certain temperature, the fly would act normally; above that temperature it would be mutant and "drop dead." The researchers would let the flies develop normally, then raise the room temperature: brain sections of those that died would be stained for the enzyme to see where it was deficient, and therefore what parts of the brain were mutant. Surprisingly, they found some mutant flies that dropped dead regardless of temperature.

To begin to find out why this happened, the team took a close look at the brains of the "drop dead" flies, and discovered them to be full of holes, like Swiss cheese. Among those with heads divided externally half and half, 80 percent lived normally and 20 percent died as if the entire head was mutant. Drs. Hotta and Benzer interpret that to mean that there are two sites, one on each side of the brain, and both must be mutant for the defect to occur. If the split is through the center, the one normal site is able to supply what is necessary to keep the brain intact. Only if the internal dividing line swings out around in such a way that both centers are mutant will the brain degenerate. This suggests some kind of interaction between the two sides of the brain, perhaps some neuro-circulatory substance. Now the group would like to find out what that substance is, perhaps by injecting extracts from the brains of normal flies into the mutant flies to see what substance protects the "drop dead" mutant.

Dr. Benzer is cautious about drawing too exact a parallel, but points out that the behavior of his "drop-dead" fruit flies is very similar to the phenomena of Huntington's chorea, a human disease. In a way, his team's model system–the fly–may give some relevant answers in spite of its distance from the human system.



In top micrograph, black grains of radioactively "tagged" thymidine–one of the constituent parts of DNA–are scattered randomly throughout multinucleated cell tissue. Below, after tissue has been exposed to damaging ultraviolet radiation, concentration of grains in nuclei is evidence that damaged DNA has undergone repair. (Photo, Frank Stockdale, Stanford University Medical Center)

Multinucleated Cell Tissue

How the body regulates or paces the rate of cell division is one of the most pervasive questions of biology. On the mechanisms of cell division rest all of the questions of how cells differentiate to form different types of tissue as an embryo develops into an adult individual, and also how normal replacement of cells sometimes goes awry to produce biologically defective cells including those of cancer. A classical area for research on the development of tissues has been the long-known fact that the multinucleated muscle cells of higher vertebrates–including man–arise from the fusion of many primordial cells, each with a single nucleus. Detailed studies of these tissues showed that the primitive, single-nucleus muscle cells divide at regular intervals, but once they have united to form the fused multinucleated muscle cells, all nuclear and cell divisions are abruptly halted.

In 1970, Frank Stockdale at Stanford University School of Medicine showed that when the mononucleated primitive cells fuse to form muscle tissue, they lose all but 15 percent of their original amount of an enzyme called DNA polymerase, which is known to be one of the ingredients required for the replication of chromosomes and the ensuing business of cell division.

This discovery raised a number of new problems, including the important one of whether cells lacking the bulk of the enzymes necessary for duplicating chromosomes can repair accidental damage to them. The integrity of chromosomes is important not only for duplication of the cell, but also for the regulation of the cell's activity during its lifetime.

Dr. Stockdale drew on the work of others showing that when DNA is artificially damaged (such as by exposure to ultraviolet light) the abnormal segment of the macromolecule is snipped out and the resulting gap is filled in by a newly synthesized stretch of the proper material. Dr. Stockdale experimentally exposed multinucleated muscle cells –from a tissue culture of the pectoral muscle of embryonic chicks– to ultraviolet light. He then "fed" the tissue culture with radioactively labeled DNA-precursor material. When, after an appropriate period of time, he separated the DNA from the cells, he discovered that the radioactively labeled material had been incorporated in the DNA, and that the DNA had therefore been repaired.

The fact that these repairs were indeed made leads Dr. Stockdale to the conclusion that while muscle cells cannot divide because they do not have enough of the enzyme needed to double DNA, they can nevertheless synthesize short segments of the material for repair purposes.

Of course, these results do not conclusively show that the 15 percent remaining amount of the enzyme is responsible for the repair function. It may indicate that there is a special DNA synthesizing system in higher vertebrates which is set into action by damage to the chromosomes of a specialized body cell. The data can also be interpreted as suggesting the existence of two different DNA-synthesizing enzyme systems in vertebrates.

Tropical Ecology

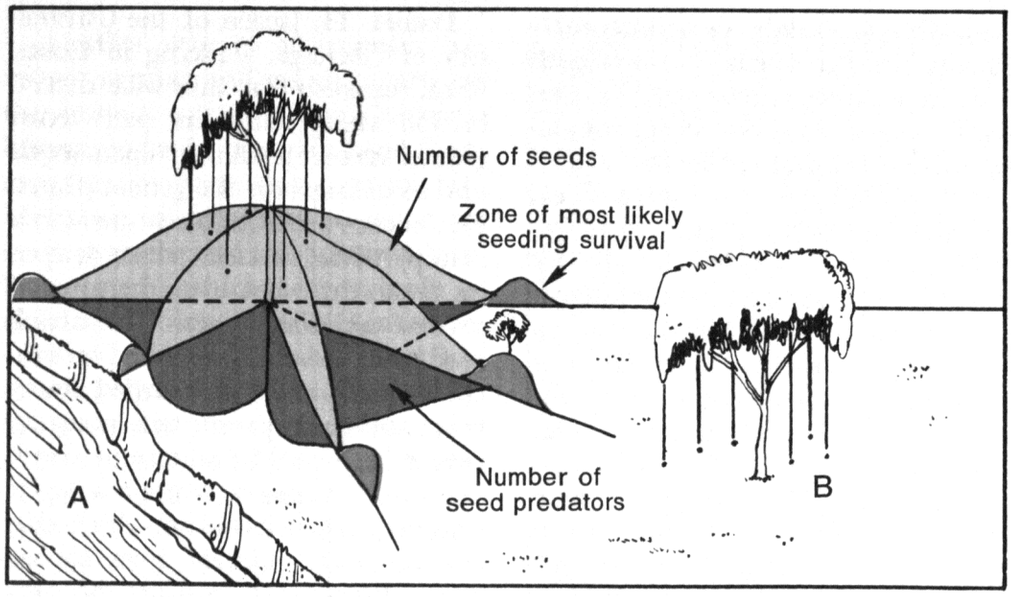
One of the great differences between the ecology of the temperate zone—such as the United States—and that of the tropics is that in the former a given unit of ground is dominated by a few plant species. In the tropics, a similar area has many species, each represented by only a few individuals. Temperate zone agriculture–the familiar field of grain–depends upon this phenomenon. If a tropical food-crop agriculture is ever to be attained, it will have to take into account the nature of the interactions between plant and animal life that generate this diversity of the naturally occurring system.

Daniel H. Janzen of the University of Chicago, working in Costa Rica, suggests that this wide distribution may result in part from greater insect predation upon seeds and seedlings near the parent plant. His most recent studies are of a canopy vine, *Dioclea,* which drapes its flowered crown over the tops of several adjacent trees. The thick seed pods drop to the ground on maturity and many are carried away from under the parent tree by squirrels as a would-be source of food. However, the seeds contain a toxic amino acid, canavanine, which discourages the animals from eating them. These seeds produce the new crop of vines, because most of the seeds left behind are eaten by a species of beetle able to cope with the canavanine and which lives almost exclusively on *Dioclea* seeds. The few surviving seedlings are destroyed by caterpillars that drop to the ground from the parent vine, on whose tender shoot tips the adult moth primarily lives. Only those seedlings that germinate far from an established vine have a reasonable chance of surviving. Inevitably, the vines therefore become widely spaced through the forest.

Larry L. Wolf of Syracuse University is studying the two distinct patterns of distribution of several species of a relative of the banana tree, called *Heliconia.* In one species, the individual trees are scattered through the tropical forest like *Dioclea.* Other species do not depend on seed for reproduction at all –possibly an evolutionary response to heavy seed predation–but reproduce vegetatively and grow in large clumps.

Each *Heliconia* flower lasts for less than a day, and produces nectar only from early morning until shortly after noon. The two types of *Heliconia* therefore provide distinct patterns of nectar distribution for the various species of hummingbird that feed from them.

Dr. Wolf has determined that the long-tailed Hermit Hummingbird,



The number of seeds of the tropical canopy vine, *Dioclea,* that fall to the ground per unit area decreases sharply with increasing distance from the parent vine (light-colored zone). Predators on seeds and seedlings (caterpillars and weevils) are similarly distributed (dark-colored zone). There is therefore an area, ringing the parent vine at a distance, in which a seedling is most likely to survive (Hatched zone). The possibility of survival is influenced by topographic features such as rivers (A), which inhibit the spread of both seeds and predators, and other adult vines of the same species (B).

which feeds from the dispersed *Heliconia,* differs in both its mating behavior and its food-gathering habits from those species that depend on the clumped plants. Each breeding male of the species feeding from *Heliconia* clumps maintains a flower-centered territory in which he feeds and from which he drives all other males of the same species. On the other hand, the male Hermit Hummingbird does not maintain a flower-centered territory, but flies a "trapline" over an extensive area, collecting the nectar as it is produced by the ephemeral flowers. During the breeding season, males congregate in groups called "leks" to call and display. The female Hermit is drawn to the group of males which attract her attention as she flies her own "trapline."

Dr. Wolf concludes that the breeding system with flower-centered territories is more primitive within the hummingbird family. The evolution of "traplining" for nectar by males and their formation of leks have been determined by the dispersed nature of the specialized energy source that they exploit.

Drs. Wolf and Janzen's studies provide another step towards the understanding of these mechanisms and, potentially, how they might apply to agriculture and man.

ENVIRONMENTAL SCIENCES

Man's surroundings—the earth which he inhabits and the envelope which surrounds it—are the concern of the environmental sciences. The scientists conducting atmospheric, earth, and oceanographic science research supported by NSF are primarily based at universities, oceanographic institutions, or at the National Center for Atmospheric Research at Boulder, Colo. In some cases, environmental studies are large-scale field operations, require the use of ships, aircraft, satellites, rockets, and other facilities, and involve scientists from many disciplines and many nations. Because of their complexity and the sheer physical size of many of the problems which must be investigated, the NSF has established several National Research Programs to bring to bear the diversity of talents needed. (Details of these programs are presented on pages 39 through 44.)

In the atmospheric sciences, 143 grants were made for $9.2 million, an increase of 25 grants and $1.2 million over the previous year. Continuing emphasis is placed on problems of atmospheric chemistry and the production, behavior, and fate of atmospheric constituents, whether occurring naturally or added inadvertently. Increased effort is being focused on the interactions between the lower and upper atmosphere and between global-scale and medium-scale weather. In part, these investigations—which require extensive field measurements using radar techniques and highly instrumented aircraft—are concerned with the behavior of the atmosphere which leads to severe storms.

Through a broad program of solar-terrestrial research, involving both theory and observations, substantial increases in knowledge have been obtained concerning the outer atmospheres of the sun and the earth. In this connection, NSF coordinated all U.S. research programs for study of the total solar eclipse on March 7, 1970. Those investigations covered such diverse topics as stellar occultations, spectrophotometry of the distant solar corona, and ionospheric waves. The findings of these investigations are under review and study. Scientifically, the eclipse research program was a great success, and preliminary planning is under way for an extraordinarily long-duration eclipse predicted for Central Africa on June 30, 1973.

In other studies of the ionosphere, there is a rapidly growing recognition of the power of the incoherent-scatter radar technique to provide a great deal of valuable information about the upper atmosphere. The dominant scientific problem in the outermost atmosphere is the magnetospheric substorm, which produces

brilliant auroras, radio blackouts, and large fluxes of electrons. Because of its pervasive effects, it can be expected to attract particular attention in the future.

As compared to 1970, the earth sciences program remained comparatively stable, awarding 225 grants in the amount of $8.0 million during fiscal year 1971. This level represents 30 to 40 percent of funds for geological research going to the nation's universities. Because the Foundation is the major supporter of geologic research in academic institutions, the effect of the change in the pattern of support by other agencies has been smaller in the earth sciences than in some of the other disciplines. Other programs which make important contributions to our earth science understanding include the Ocean Sediment Coring Program (page 42) and portions of the International Decade of Ocean Exploration (page 39).

The past decade has witnessed remarkable advances in the science of geology. Most significantly, the concept of seafloor spreading and plate tectonics provides, for the first time, a theoretical framework for viewing major tectonic processes on a global basis. With this unifying concept it is possible to explain a wide range of diverse observations on earthquakes, volcanism, faulting, mountain building, and the basic processes that shape the surface of our planet. As is often the case when a new theory of wide scope emerges, further research is required to test the main line of the theory more fully and to extend it so as to integrate it with other observations. Although seafloor spreading and plate tectonics has been most successful in dealing with the oceanic areas, its pertinence to continental deformation is not clearly demonstrated in all cases.

Oceanographic research project support is related to and coordinated with the Ocean Sediment Coring Program, the International Decade of Ocean Exploration, and the Arctic and Antarctic Research Programs. The oceanography research project support concentrates on studies of organisms living in the ocean, the origin and structure of ocean basins, energy interactions between the sea and the land and the atmosphere, and above all, the physical processes that keep the global sea in motion. In pursuit of these objectives, grants for $9.9 million were awarded in fiscal year 1971—which is $1.0 million more than the support of the year before.

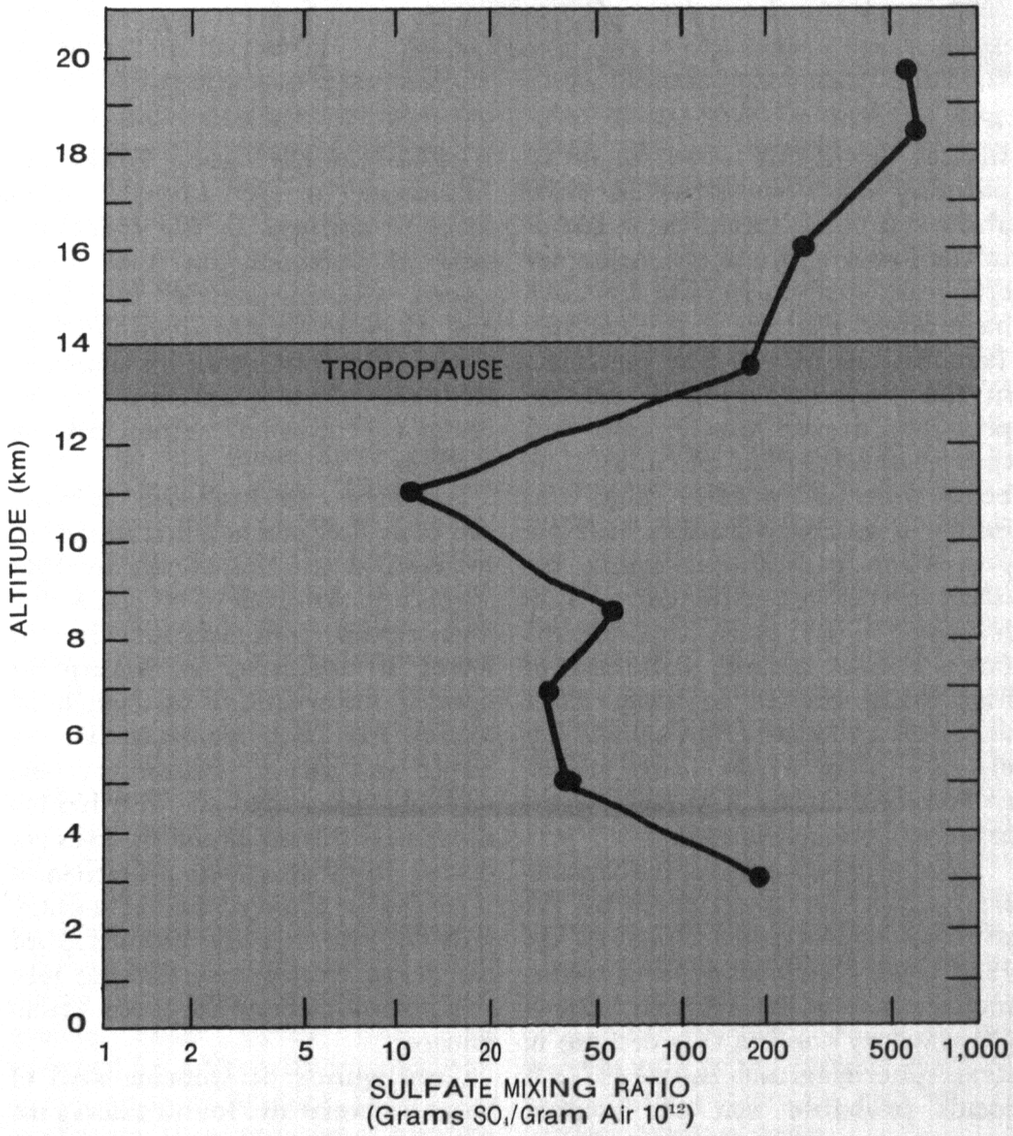
From these kinds of studies it is hoped, among other things, to learn more about the dynamic processes controlling the deep circulation and turnover of ocean waters, sediment concentration, replenishment of surface nutrients, and energy exchanges. Concern with dynamic functioning of ocean systems is also reflected in marine ecological studies. A great deal of emphasis is also being placed on the effect of higher nutrient concentrations, insecticides, and trace metals on marine bacteria and microorganisms. With this increase in our understanding of the oceans and the objects and phenomena associated with them, it is anticipated that the United States can move forward in its efforts to develop and use the vast resources of the sea.

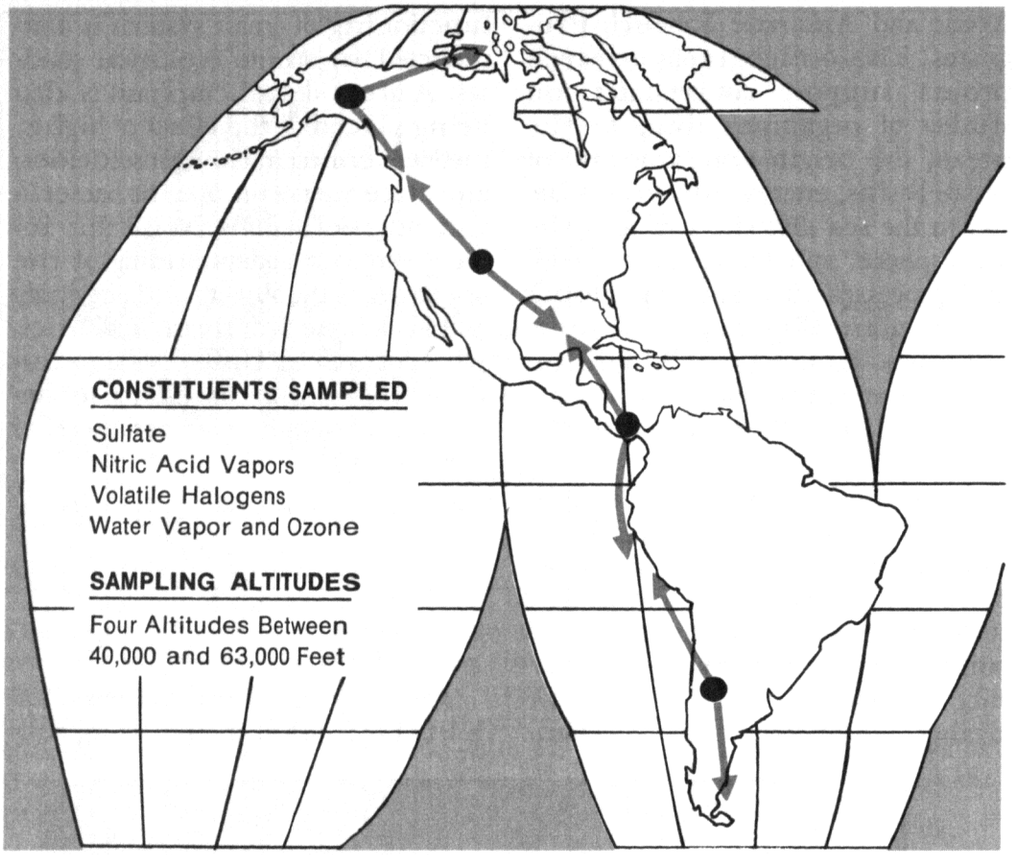
ATMOSPHERIC SCIENCES

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Stratospheric Aerosols

Although man must take responsibility for much of the polluting sub-





stances in the air today, he is apparently not responsible for some abnormal constituents being found in the lower stratosphere. After several years' study, scientists at NCAR have found that the major aerosols (suspensions of very fine particles) in the lower stratosphere, sulfates, probably derive mostly from volcanic fumes. Sulfate particles have been collected directly from the fumes of several volcanoes, and the proportion of different sulfur isotopes in volcanic sulfur compounds is similar to that of stratospheric sulfate. Aerosol samples collected by high-flying aircraft in 1966, 1969, and early 1970 show that sulfate levels in a layer in the lower stratosphere were almost 10 times as great as were measured in 1961.

Late in 1970, however, the concentrations in the lowest levels of the stratosphere decreased almost to the 1961 level. Other kinds of measurements made at NCAR and Lowell Observatory confirm this decline in stratospheric aerosols in late 1970. It seems probable that the violent eruption of the Agung Volcano in Indonesia in 1963 brought about marked changes in the concentration of particles, and that subsequent volcanic activity in Alaska and elsewhere maintained the high levels. The concentrations measured most recently may represent a return toward a "normal" aerosol concentration.

Another stratospheric aerosol, nitric acid vapor, was first identified by optical studies of the twilight spectrum. Analyses of NCAR's samples reveal concentrations in the lower stratosphere, confirming the optical observations. Although no source has been identified for the nitric acid vapor, preliminary data on its geographical distribution show that it, too, probably does not derive from manmade pollution; it is found in almost equal concentration in the heavily industrialized Northern Hemisphere and the relatively unpopulated Southern Hemisphere.

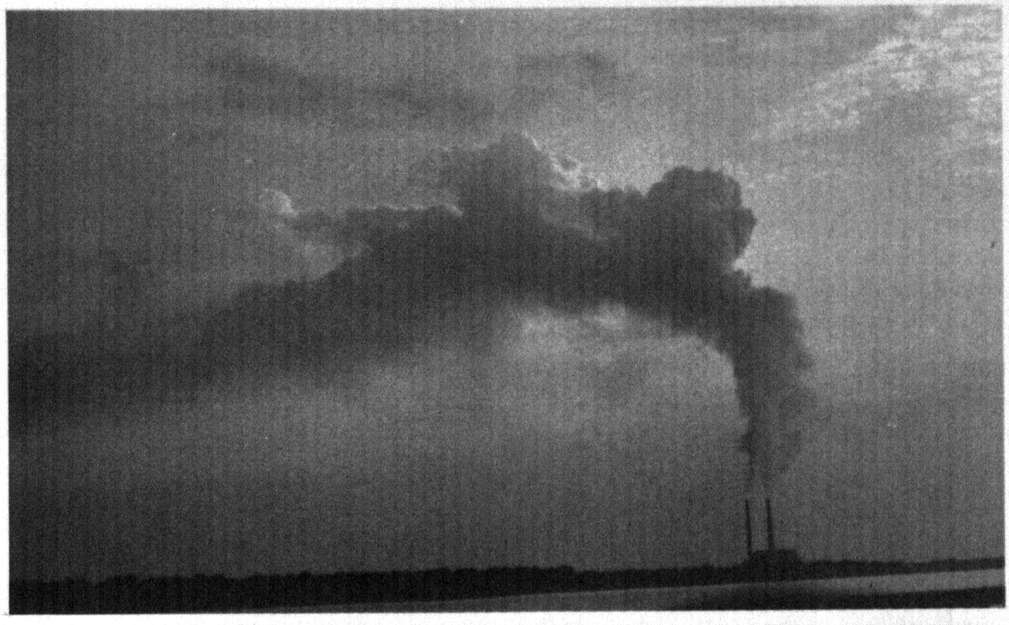
Compounds of chlorine and of bromine were also found among the aerosols collected, with the average chlorine-to-bromine ratio (by mass) about 20 to 1. Since the corresponding ratio in sea salt is about 300 to 1 and that in crustal rocks and soil is about 70 to 1, stratospheric chlorine and bromine probably do not originate from either sea salt or continental dust. They may, however, come from manmade pollutants (especially automobile exhausts) or from volcanic fumes.

Solar Wind

Interplanetary space, far from the complete void it was once thought to be, is filled with ionized gas known as the solar wind. This wind, which consists mainly of protons and electrons emitted from the sun, is the result of continuous expansion of the solar corona. When scientists at NCAR's High Altitude Observatory used satellite observations to study variations in the speed of the solar wind—which ranges from 250 to 850 kilometers per second—they found that, unlike most other solar phenomena, the solar wind speed is nearly independent of the 11-year cycle of solar activity. The yearly average speed is close to 400 kilometers per second whether the year is near solar minimum or solar maximum activity. These findings suggest that solar activity in general, and increases in the density and temperature of the corona in particular, do not grossly affect the overall rate of emission of material.

Although the yearly average is nearly constant, the solar wind speed can vary considerably from one day to the next. Rotation of the sun provides one source of variation at the earth, even when solar conditions are steady; the general evolution of the solar atmosphere provides another source. The NCAR studies have shown that the solar wind emission from the sun typically remains about the same over some 35° in solar longitude. Because the sun rotates at an average rate of 13.3° per earth day, the solar wind speed ob-

served at the earth's orbit is reasonably steady for about 2.6 days. The studies also suggest that the speed of the wind emanating from a particular solar region usually changes significantly within 4 earth days, so specific speed patterns are usually not observed when that portion of the sun eventually rotates back into view. When the patterns do recur on successive rotations, they are more likely to include lower speeds (less than 400 kilometers per second) than higher, implying that the regions of quiet coronal expansion can persist considerably longer than other regions.



An effect of urban activities on weather phenomena is visible at this major power plant along the Mississippi River near St. Louis, where cumulus have been frequently observed growing out of the plant's effluent. (Photo Illinois State Water Survey)

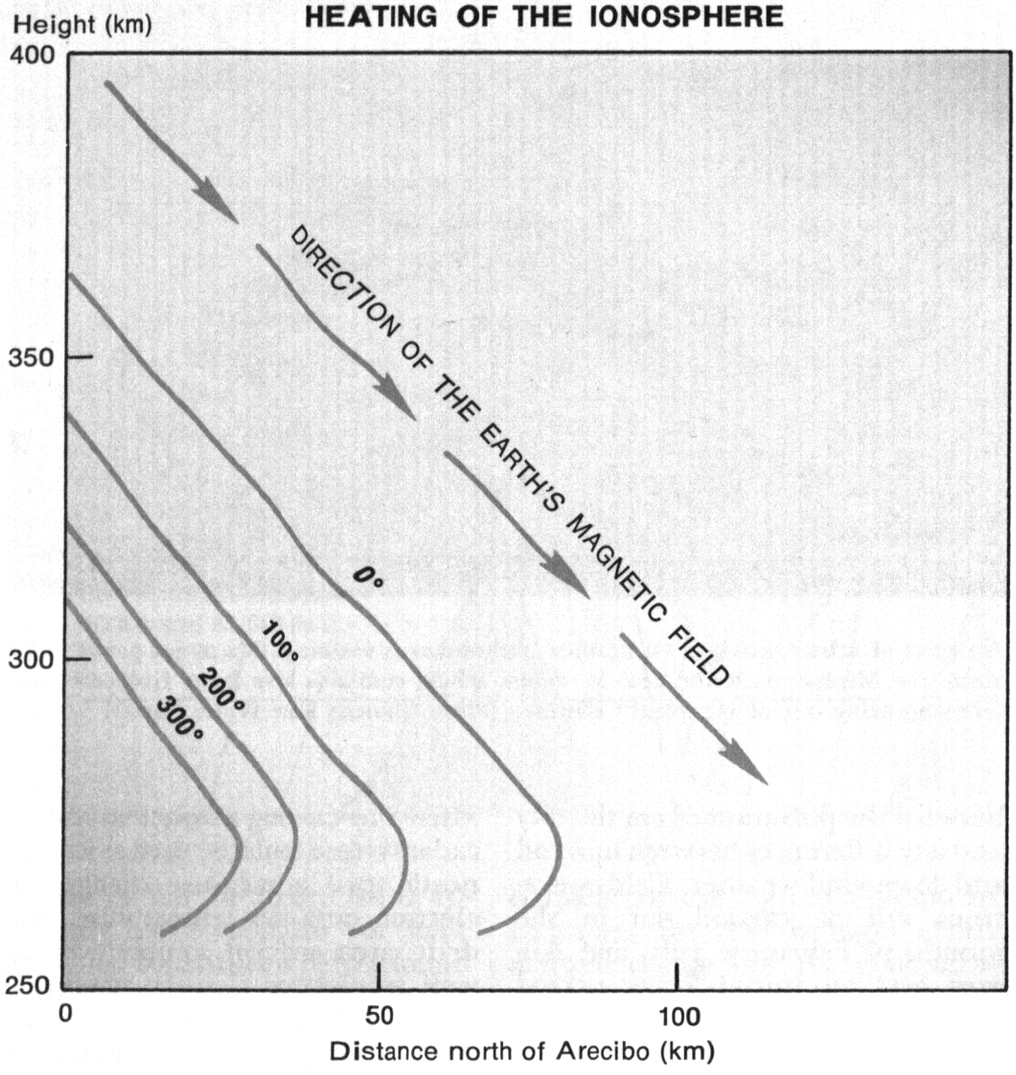
University Research

Modifications of the Atmosphere

Several projects aimed at discovering the causative factors of inadvertent weather modification—the necessary first steps towards solving the associated social, economic, and ecological problems—have moved into the field experiment stage in the St. Louis urban area. Scientists from the University of Illinois are examining summer precipitation and related severe weather events there, and they will evaluate rainfall and radar data to determine the magnitude of urban-related precipitation changes under different weather situations. A group from the University of Chicago will study the same urban area by measuring and studying the internal structure of clouds and precipitation regions upwind versus downwind of St. Louis. Data on cloud condensation nuclei, cloud particle spectra, cloud water content, precipitation particle spectra, ice crystal nuclei, ice crystal content, meteorological state parameters, solar radiation, and surface albedo will be obtained from an instrumented airplane. These will be compared with ground-based radar measurements of the location and intensity of precipitation regions in an effort to pin down cause-and-effect relationships between the pollutants from the city and any differences between upwind and downwind weather. Field operations will be carried out in the months of February, July, and August over an initial 2-year period that began in 1971.

Inadvertent modification of the atmosphere in and around St. Louis may be contrasted to the deliberate but short-lived and harmless modification of the ionosphere above Arecibo, Puerto Rico. There, the ionosphere (the region of the atmosphere above about 70 kilometers which contains free ions) is heated by a high-power radio pulse. The heated region is then probed by sending a radar pulse into the region of interest and measuring intensity and spectral shape of the weak return as a function of time (the technique of incoherent radar backscatter). NSF grantees have made substantial contributions to the development of this technique.

Substantial heating of the ionosphere by absorption of high-frequency radio waves was first achieved by a Department of Commerce group in Boulder, Colo.; the heating was then repeated at Arecibo where the existing incoherent scatter radar system could be used as a diagnostic tool to measure changes in electron and ion temperature, ion drift rates and ion composition, as well as electron density associated with the heating. The radar measurements indicated that ionospheric plasma waves at the plasma frequency were increased by two orders of magnitude during the heating, and that while the change in ion temperature was small, the maximum increase in electron temperature was from 1,100° to 1,400°, or almost 30 percent. It was concluded that the heating of the electron gas was not due to electron collisions with ions and uncharged particles as originally expected, but that a two-stage process was involved. First, the radio-frequency wave produced amplification of plasma waves in the medium, then the amplified waves interacted with the ambient electrons to transfer energy to them. This heating experiment demonstrates the utility of the incoherent backscatter technique as a powerful tool for measuring a large number of ionospheric parameters over an extended region of space.



On October 22, 1970, at Arecibo Observatory, high-frequency radio waves transmitted from the ground and absorbed in the ionosphere produced the increases in electron temperature shown by the contours. The maximum rise of 300° K. represents a 30 percent increase in temperature. Maximum absorption (and, hence, maximum heating) occurred vertically above Arecibo at a height of 300 kilometers, where the input was strongest. Because heat is conducted rapidly in the direction of the earth's magnetic field, the temperature remains essentially constant along the field down to about 270 kilometers. Below that altitude, rapid cooling takes place as a result of increasing density of the neutral atmosphere.

EARTH SCIENCES

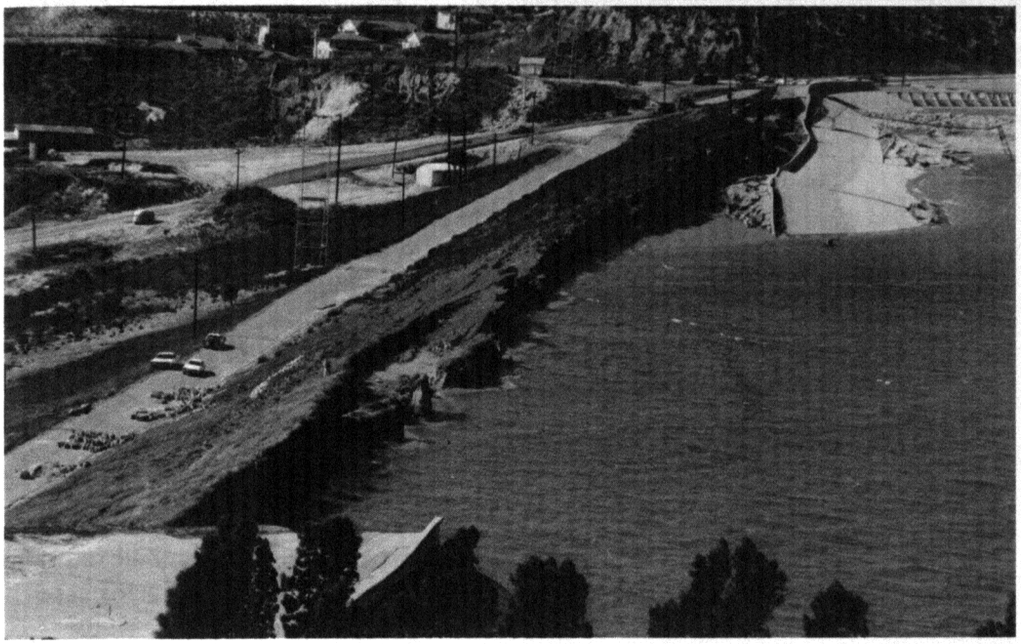
Earthquake Studies

The importance of the earth sciences to man was brought out dramatically during the past year with the occurrence of California's San Fernando earthquake on February 9, 1971. This earthquake, with a Richter magnitude of 6.6—a modest event by seismological standards—was nonetheless a great disaster, with nearly a billion dollars in damage. The loss of 64 lives, the sixth highest in the United States' earthquake history, could easily have been multiplied many times because 80,000 people were threatened by the near-failure of the Van Norman Dam.

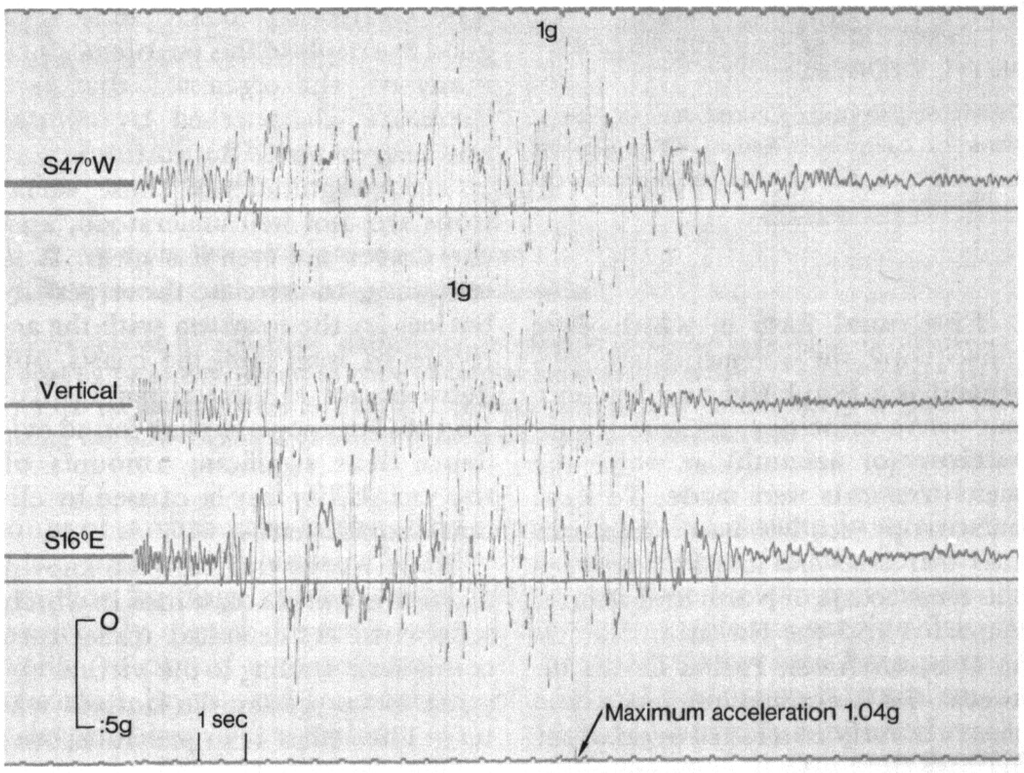
This earthquake has extreme importance for seismology and for earthquake engineering because it occurred in an area that was comparatively instrumented with accelerographs, strain meters, tiltmeters, and other geophysical instruments. It provided unusual opportunities for obtaining information of immense practical as well as scientific value. For example, the greatest ground acceleration ever recorded was reported from the epicentral region, with some high-frequency vibrations exceeding that of gravity. Ground accelerations that great were unknown from previous California earthquake records, and the knowledge that such extreme acceleration can occur is forcing major reevaluations of earthquake hazards and engineering design.

Geophysicists at the California Institute of Technology's Seismological Laboratory, which operates the main seismograph network in southern California, responded quickly to this earthquake. Not only were they able to pinpoint the epicenter immediately because data from some of the key stations were telemetered to the Laboratory in Pasadena, but also within 3 hours of the main shocks they had mobilized portable geophysical equipment and installed it in critical field locations. Caltech geologists were also in the field within 3 hours of the earthquake to assist in obtaining critical aftershock and other data needed for complete geological and geophysical analysis of this earthquake event. The immediate attention of Caltech staff and students to the San Fernando earthquake resulted in the collection of significant data and publication of reports by April 1971, covering the seismological environment, preliminary seismological and geological studies, main shock and aftershocks, patterns of faulting, precise locations of aftershocks, orientation of the fault planes, and strains and tilts of the earth.

An unusual aspect of the earthquake was the extent and complexity of surface faulting which shattered the area, inflicting abnormal amounts of damage to buildings, highways, power lines, and other



The badly damaged Lower Van Norman Dam shortly after the San Fernando earthquake of February 9, 1971. (Los Angeles Water and Power Department photo by Max Gould)



This February 9, 1971, accelerograph record from the abutment of Pacoima Dam shows the greatest earthquake strong motion (1.04 g) ever recorded. Evidence of such large acceleration from a moderate earthquake has important implications for protection against future earthquake hazards.

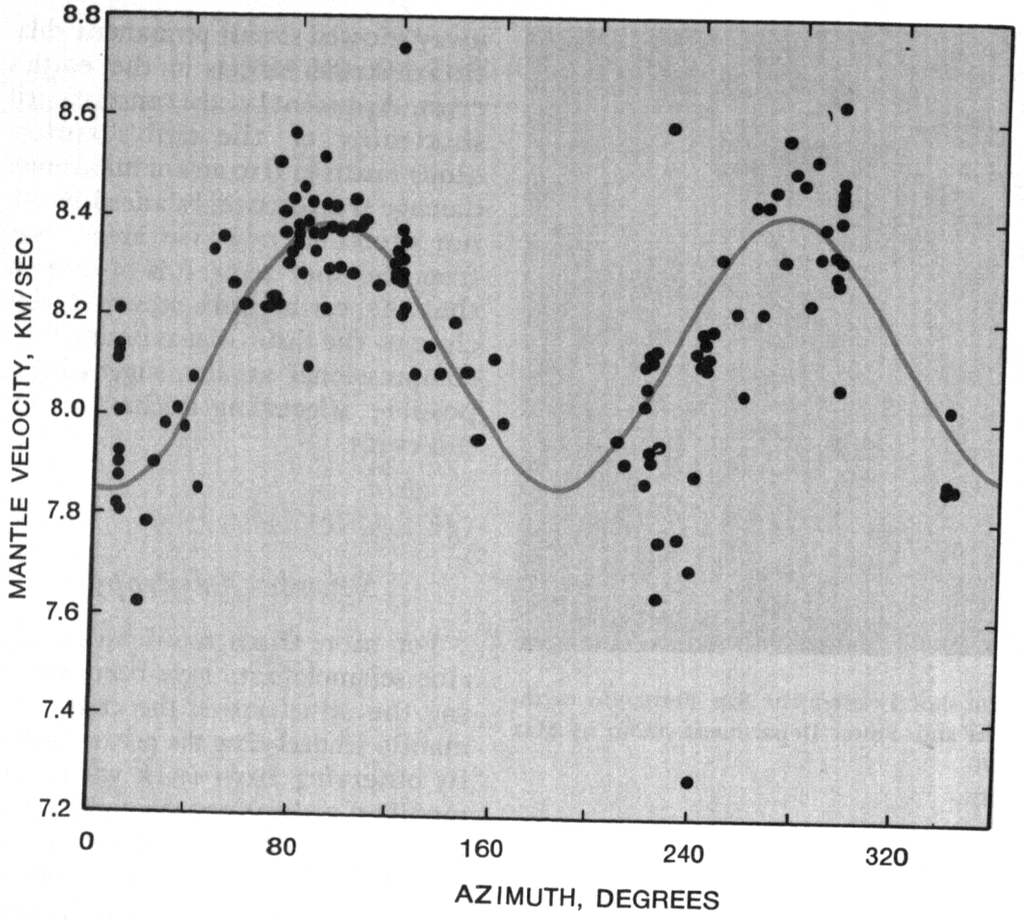
structures built in the path of the faults. In some places the vertical offset on faults was as much as 35 inches, horizontal offset along the trend or strike of the fault as much as 64 inches, and compression of land area across faults as much as 42 inches. Stations as far as 250 miles away showed small permanent dilational strain effects in the earth's crust. Apparently, the concentrated shortening of the earth's surface along faults in the area of maximum damage was counter-balanced by minor stretching over vast areas away from the fault zone. It is of interest that the earthquake occurred very close to the time of maximum tidal compressional strains, suggesting a possible triggering mechanism for this event.

OCEANOGRAPHY

Seismic Anisotropy

For more than two decades, marine seismologists have been studying the structure of the crust and mantle underlying the ocean basins by observing how shock waves are modified as they pass through. A significant part of the information obtained has involved the determination of the velocity at which compressional waves travel through the rock material forming the outermost part of the earth's mantle. As these data accumulated, it became apparent that there were substantial variations in the magnitude of this mantle velocity from place to place. For many years, these variations were attributed to presumed differences in rock materials from one area to another because there seemed no other reasonable explanation.

In the mid-1960's, with the introduction of the concept of seafloor spreading, it was pointed out by the late Harry Hess of Princeton that a significant part of the variability in mantle velocities might be explained if the rock material in the upper mantle were anisotropic (having different physical properties in different directions) in a regular sense over widespread regions of the ocean basins. Dr. Hess also suggested that this anisotropy might be directly related to large convective cells in the mantle, which many earth scientists believe to be the driving mechanism



Anisotropy measurements from one Pacific Ocean region near Central America show the seismic wave velocity variations as functions of compass direction. (The greatest variations recorded to date are near Hawaii—a high of 8.45 km/sec nearly east-west and a north-south low of 7.85 km/sec.)

for seafloor spreading, and which could reasonably provide a widespread mechanism for the flow-induced alignment of anisotropic crystal grains such as olivine. This crystal alignment would in turn produce an observed whole-rock anisotropy.

Since this hypothesis was suggested, Russell Raitt and George Shor and their associates at the Scripps Institution of Oceanography have been developing and testing the necessary techniques for acquiring and analyzing seismic anisotropy data with the required accuracy. These developments have evolved to the point where adequate anisotropy measurements can be made using one ship and sonobuoys rather than the two ships required before, and where data analyses, though time consuming, have become standardized.

The usual form in which these anisotropy measurements are presented is a graph showing how seismic wave velocities vary with the direction (or azimuth) at which the measurements were made. To date, anisotropy studies have been carried out at several locations between the west coasts of North and Central America and the Hawaiian Islands, in the northwest Pacific Ocean between the Aleutians and Japan, and most recently in selected areas of the Indian Ocean. In all of these studies, the anisotropy observations are consistent with the hypothesis that the maximum velocity is in the direction of seafloor spreading. The magnitude of the anisotropy observed has been variable.

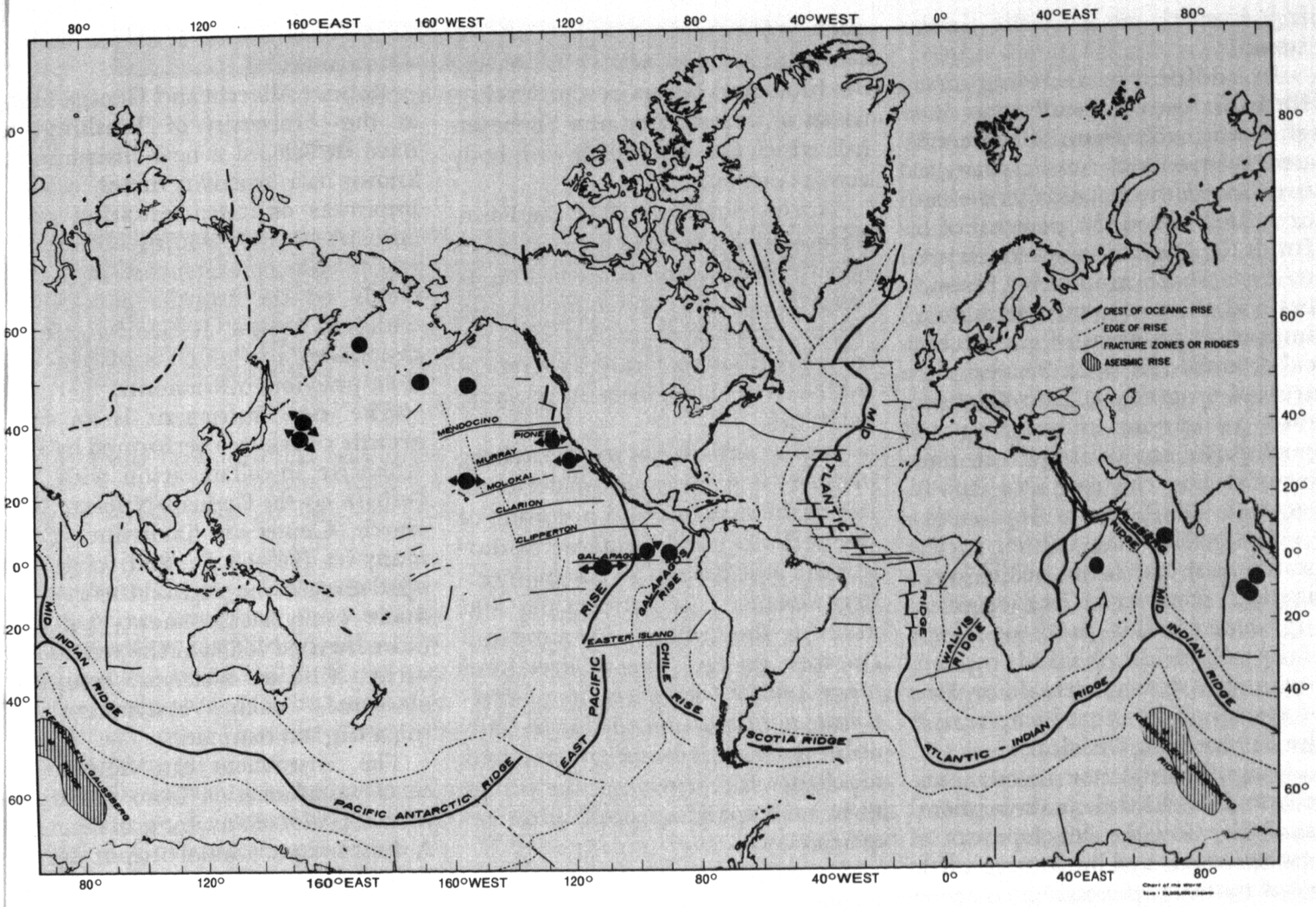
The potential significance of an anisotropic mantle is considerable. It holds the promise of providing independent and quite valuable information and constraints on the directions of seafloor spreading and the mechanism by which crustal plates are moved about. In addition, quantitative information on mantle anisotropy and its variability would contribute substantially to the accurate prediction of the rock densities used in gravimetric analysis of structural models of the earth's crust and upper mantle.

Natural Variability of Coastal Resources

Commercial fisheries, which are important regional industries as well as large producers of food for human and animal consumption, are particularly vulnerable to the variability of coastal ecosystems. The amounts and distributions of species of sea life differ from year to year. The California coastal zone is a good example of this problem, since many of the organisms that live there are characterized by annual and longer-period fluctuations.

The magnitudes of these variations are not well understood, and the causes are even less clear. It is tempting to correlate these perturbations in the ecosystem with the activities of man along the coasts, but John Isaacs at the Scripps Institution of Oceanography has found evidence that significant amounts of the variability may be caused by climatic conditions.

There are several locations known along the world's coastlines in which sediments are deposited under rare conditions leading to the virtual absence of oxygen in the bottom waters. The effect is to preclude burrowing and bottom animals from disturbing the fresh sediments, and also to inhibit the decomposition of any organic remains. One of these unusual offshore basins is at Santa Barbara, and there Dr. Isaacs has been studying the remains of organisms preserved in the annually layered sediments for evidence of past abundances. He found that the



● Anisotropy Stations (data reduction in process)

● Anisotropy Stations with resultant high-velocity vector

Measurements of the anisotropy (differences in physical properties depending on direction) of the upper mantle were made at 16 oceanic sites by June 1971. Results to date show that maximum seismic wave velocities are in the directions of the spreading of the seafloor away from the oceanic ridges and rises. This is in agreement with the concept of giant convective cells within the earth, which may be inducing the flow-alignment of anisotropic crystal grains in the mantle.

amount of sardine scales in the sediments correlated with historical data on sardine landings, and by studying specially "quick frozen" core samples (to protect unconsolidated near-surface layers) and by analyzing deeper, hence older, portions of the cores, he has been able to estimate probable sardine abundances in the past. Sardines, he finds, were extremely abundant during the 1860's and 1890's, and each peak was followed by a drastic reduction. Moreover, these peaks occurred during periods of high rainfall, which is recorded in annual growth rings of trees of the immediate area. It now seems likely that changes in sardine abundance reflect climatic fluctuations and that the precipitous decline of the California sardine fishery in the 1930's may have been part of a natural population fluctuation.

Dr. Isaacs' currently supported research is designed to elucidate fluctuations in other organisms off California and to evaluate fluctuations of commercially important species in other areas. The techniques developed for studying the layered sediments and correlating them with various climatic measures in addition to rainfall should be useful in the study of other regions—such as Peru, India, or southern Africa—that contain important fisheries. Determination of the natural fluctuations of the fish may lead to greatly improved scientific management of these ocean resources.

ENGINEERING

During fiscal year 1971, the NSF awarded 425 grants, totaling $17.4 million for engineering research. This represents a level of effort similar to that of the preceding year, and accounts for about 15 percent of the direct Federal support for engineer-

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ing research at academic institutions.

In addition to awarding grants for basic research in all areas of engineering, the Foundation continued its trend of recent years and broadened the scope of its research activities. About 30 percent of the funds for engineering were devoted to areas where engineering researchers and their students can have an impact on problems of great technical or social relevance. Some of these areas of programmatic investigation, such as enzyme engineering and earthquake engineering, were transferred during the year to the new Directorate of Research Applications (see page 57), while others, such as materials research, biomedical engineering, communications engineering, construction methods (especially tall buildings), wind engineering, and hydrology, remain as areas of special and enlarged emphasis in the Engineering Division.

A significant factor in our economy and world trade is the national capability for the development of new materials and innovative methods of material processing. In recent years, dominance in materials processing has been severely eroded by technological advances by foreign competitors. Of particular importance is machining of superalloys using superhard materials—an area which requires much research in the development of new materials and improved understanding of existing materials. For some uses it has been found that the durability of tungsten carbide tools can be improved drastically by coating the surface with a 0.0002-inch layer of titanium carbide. It can be expected that coated tools will be used more and more in the future, but their full potential could be better exploited if it was known why a minute coating makes tools more effective.

Biomedical engineering attempts to contribute to the solution of health problems through the interplay of engineering with biology and medicine. It concerns itself with such problems as the effects of electromagnetic and ultrasonic energy on biological tissues or the development of improved or new biomaterials which are compatible with body tissues or fluids.

During fiscal year 1971, the Foundation used about 10 percent of its engineering funds to continue to provide special opportunities for young graduate engineers. This Research Initiation Grant Program is included in all engineering program activities.

Just as science has made exciting progress in gaining new understanding of the structure and operation of the technical and social world during the past 20 years, so has engineering advanced in anticipating and meeting the demands for more and cheaper energy, longer lived and more reliable materials, more effective communication, and more suitable and efficient techniques and machines for providing the things that an expanding population requires.

Measurements in Reactors

A nuclear reactor, more than any other powerful machine, is one whose internal activity must be known from moment to moment. However, the problems are different from checking the oil pressure or rate of fuel flow into a diesel engine or the rate of water flow through a hydroelectric turbine. A nuclear reactor operates silently and behind heavy shielding. Its direct output, heat, is actually a secondary product of the nuclear fission process taking place in its radioactive core. Measuring the heat produced, or the electrical current produced by the heat, is a secondary measure which actually amounts to a reading of what happened earlier in the nuclear reaction. It is important for reactor safety engineers and operating personnel to know from moment to moment exactly how the nuclear reaction—the production of thermal neutrons as a result of atomic fission—is proceeding.

Robert Albrecht and George Hess at the University of Washington have developed a new instrument, known as a "reactivity meter," which improves on instrumentation presently in use by providing both more rapid and more accurate measurements of the neutron population within a reactor. It also has applications to a larger class of reactors than previous instruments.

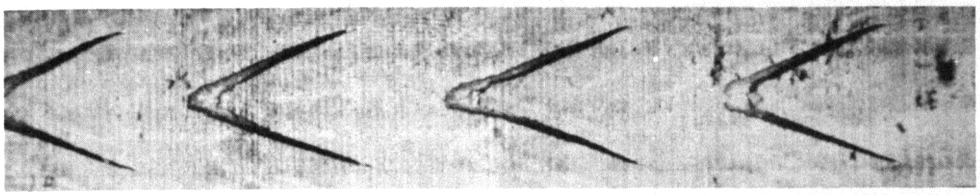
The new instrument is an outgrowth of research performed by Dr. Albrecht in collaboration with W. Seifritz of the German Nuclear Research Center in Karlsruhe, Germany in 1967–68. Dr. Seifritz developed some of the original theory and made early measurements with a more limited design of the reactivity meter. The new meter is a complex electronic "on-line" instrument using a digital computer.

The instrument can determine certain information from the neutron activity of any nuclear reactor. A detector provides an output signal which fluctuates depending on the number of neutrons within its sensitive region. The number and velocity of these neutrons provide information from which the computer can calculate the instantaneous reactivity (i.e., neutron population), the statistical standard deviation (a measure of the accuracy of the measurement), and other values. In effect, the computer and the detector count variations of the neutron population within the reactor and apply standard statistical concepts to these variations.

Dr. Albrecht's new and more advanced instrument was developed at the University of Washington, and has been tested on a number of experimental reactors.

An even more advanced version of the new meter has been tested in the University of Washington nuclear reactor by a group of engineering graduate students in the nuclear engineering department as part of their laboratory experience. These

LABORATORY SCALE



INDUSTRIAL SCALE

The "center burst defect" has been shown to be caused by the conditions under which metal is worked, or "deformed," rather than a pre-existing defect in the material. (Photo by Dr. Betzalel Avitzur, Lehigh University)

tests form the basis of the construction of an instrument that will be permanently installed for the UW nuclear reactor, as well as for meters to be made part of the instrumentation of other nuclear reactors throughout the country.

The instrument is being patented, with title to the invention vested in the U.S. Government, and rights are being transferred by the National Science Foundation to the Atomic Energy Commission.

Metal Processing

The conversion of an ingot of cast metal into useful intermediate products such as sheet, plate, bar, and wire involves a capital investment by American industry of tens of billions of dollars and operating expenses of several billion dollars annually. Despite the large investment and cost involved, the behavior of metals and alloys during the rolling and drawing processes is not well enough understood to permit improving either the process or the product in other than an empirical way. The engineering science traditionally involved has been limited to the design of equipment capable of the required dimensional change. No consideration of the behavior of the material itself was attempted. Thus, to a large extent, the development of most industrial metallurgical processes has been by the costly method of trial and error.

However, as knowledge of the behavior of materials and techniques for the analysis of plastic deformation processes have deepened, a more systematic approach has become possible. Betzalel Avitzur of Lehigh University has been working for some years developing a more rigorous analysis of some of the primary metal fabrication processes. In this analysis, Dr. Avitzur has been correlating known facts of the behavior of metals with the mechanical engineering processes being used. Dr. Avitzur's investigation has been primarily one of matching a theoretical analysis of the axisymmetric flow of materials (the plastic flow of a material which is symmetrical with respect to the direction in which it is moving) with experimental verification. The treatment resulting from Dr. Avitzur's investigation permits, for the first time, the reliable measurement and prediction of such variables in industrial processing as the forces required, the maximum possible reduction in size per processing step, optimum design of dies, flow patterns and strain rates, and the causes for some of the defects encountered in practice.

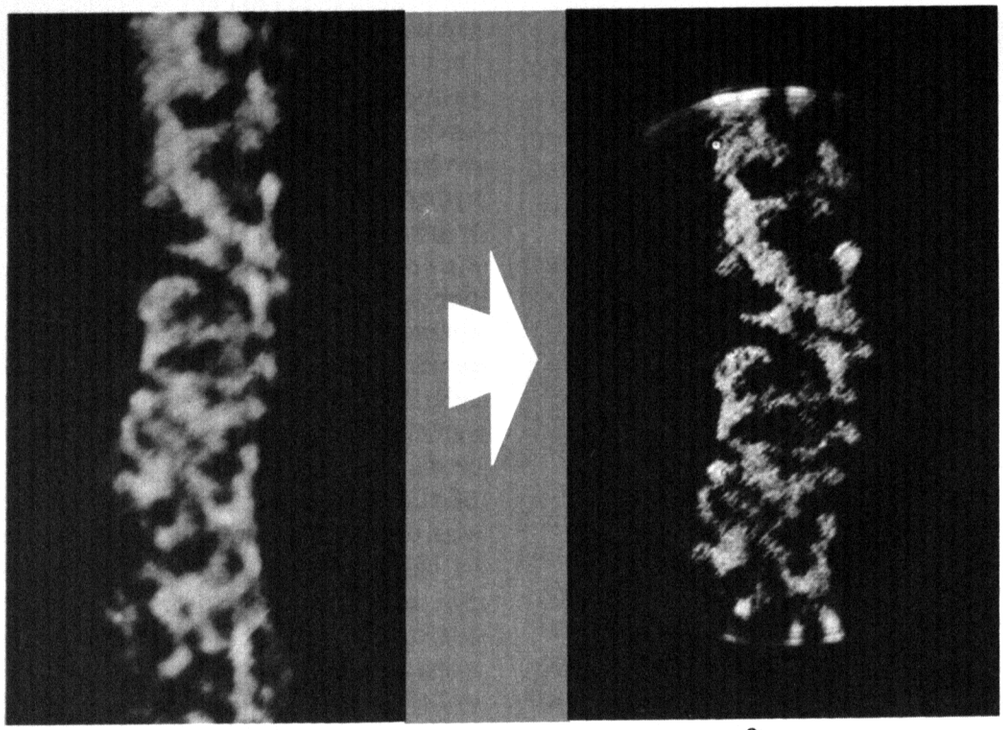
A specific achievement of Dr. Avitzur's analysis has been the determination of the cause for the "center burst defect," traditionally thought to be a problem associated with the material in question. Dr. Avitzur's theoretical analysis first suggested, and his experimental work confirmed, that this defect occurs because of the conditions under which metal is worked, or "deformed," rather than to any specific, preexisting defect in the material itself. As a result, a criterion has been developed for the process which essentially eliminates the probability of the center burst occurring in the standard extrusion process. The use of this criterion has resulted in major improvements in both the quality of the product and in the economics of cold-extruded steel.

Dr. Avitzur's analysis is also being currently applied in the aluminum industry, a major user of extrusion technology; in the optimization of tungsten wire drawing techniques in the electronic industry; and in various special metal forming processes being developed by the Air Force.

Dr. Avitzur's work is fundamentally significant in its contribution to our understanding of the behavior of materials under conditions of axisymmetric flow. Such conditions are and will continue to be of major importance in many metal fabrication processes. The application of this new knowledge offers an opportunity of improving these processes, an opportunity which is being rapidly recognized by the metal extrusion industry.

Holographic Image Sharpening

The electron microscope has brought man's ability to see the very small almost to the point where he can photograph the details of large molecules—but not quite. Unfortunately, virtually all optical systems, from the largest astronomical telescope to the most powerful electron microscope, are barred from reaching their theoretical limits of resolution (the smallest detail they can pick up) by motion, imperfect fo-



Electron microphotograph of fd filamentous virus shows highest degree of resolution—detail to 5 Ångstrom units. Following image enhancement by holographic techniques, resolution is improved by factor of two to show detail of 2.5 Ångstroms. (Micrograph by A. V. Crewe, University of Chicago. Enhancement photo by G. Stroke, State University of New York at Stony Brook)

cus, atmospheric turbulence, or instrumental defects.

This limit on resolution means that the smallest object that a biologist, using an electron microscope, can visualize is approximately the size of the amount of space taken up by two atoms. In order to visualize useful structural details of biological molecules, it would be necessary to improve this resolution by a factor of two. (This does not mean that an electron microscope with a resolution on the order of 2 Angstroms would be able to photograph an atom. The "diameter" of an atom measures a space which is effectively empty, just as the effective volume of the solar system is primarily empty space.)

George Stroke at the State University of New York at Stony Brook reasoned that the electron beam that originally produces the imperfectly resolved image in the electron microscope contains all of the information about the object that is theoretically possible. Further, he reasoned the way the information in the imperfect image is blurred by the system can be predicted mathematically. If this were true, it would be possible to "decode" the blurring by reversing the mathematics.

Accordingly, Dr. Stroke used the mathematics that describe the image-forming mechanism and the principles of holography (laser-produced three-dimensional "lensless" photography) to produce an optical filter which is essentially an analog of the reverse mathematical process. The "key" to decoding the blurring of an entire photograph is contained in the defective image of a single point. In the case of the electron microscope, a point is imaged in the form of an almost uniform circular "patch," rather than like a sharp point. The holographic "filter," if carefully manipulated, can reverse the mathematical function which describes the blurred photo, thereby shifting the image back to its unblurred state.

The most recent and dramatic example of the ability of Dr. Stroke's system to clarify electron micrographs is shown in the illustration. The photographs show a portion of the structure of the fd filamentous bacterial virus, a bacteriophage that infects the common intestinal bacterium *E. coli*. The original photograph was obtained by Albert Crewe at the University of Chicago, using a specially designed transmission scanning electron microscope with a resolution of 5 Ångstrom units. Dr. Crewe's photograph, treated by Dr. Stroke's image sharpening, achieves a resolution of 2.5 Ångstroms.

This degree of detail provides biologists with a hitherto unobtainable ability to see the details of the molecules of life in a fairly direct and simple way. Beyond this, the ability to improve resolution will have applications wherever man's instruments attempt to enlarge the scope of his eyes.

SOCIAL SCIENCES

Research in the social sciences received increased impetus by NSF during fiscal year 1971. This research covers a wide range of disciplines involving methodological, theoretical, and problem-focused work. All of it is designed to further scientific knowledge of human beings in their interaction with one another, and their customs, institutions, and organizations.

At present, the NSF provides about one-fifth of the total Federal support of social science research. In some fields, such as econometrics and anthropology, the NSF is the principal source of support. A number of factors are currently operating to increase both total Federal support for social science research and the NSF portion.

Solutions for pressing social problems require more complete and accurate knowledge of human behavior and of institutions. Fortunately, productive new research techniques in social sciences are increasingly

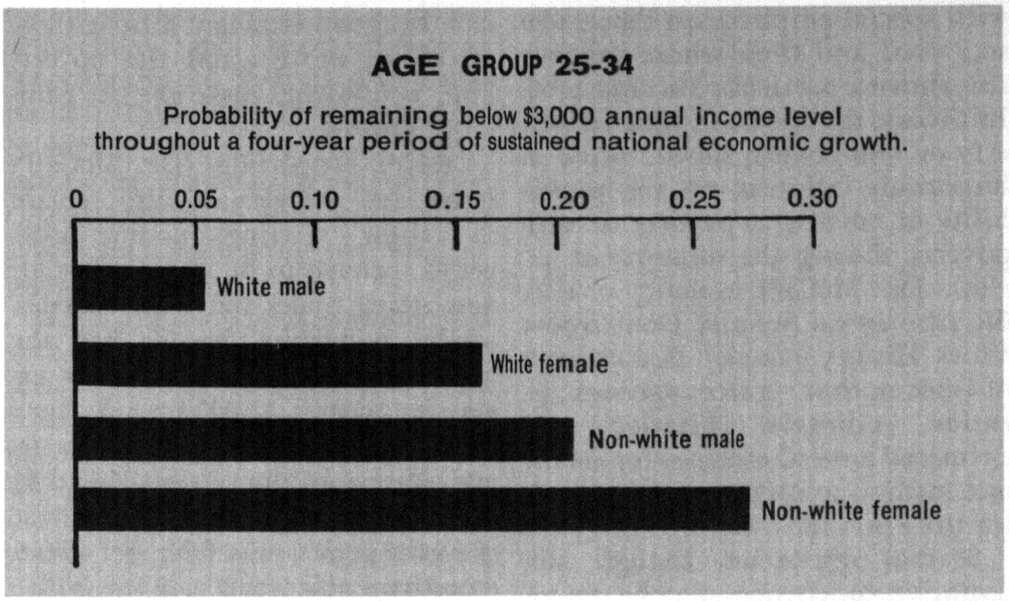
able to help in forming workable responses to current problems.

As a result of these converging trends, the broadened scope of NSF authority, and increasing awareness of the NSF's social science commitment, requests to the Foundation for support of social science have increased markedly in the past fiscal year. In fiscal year 1971 the NSF received 1,281 proposals as compared to 1,087 proposals in fiscal year 1970. A total of 484 grants, in the amount of $17.4 million, was awarded.

With this funding, a wide variety of research in the social sciences was undertaken. One important area of emphasis was the improvement of mathematical methods applicable to social science problems. For example, studies have been and are being funded to investigate the inverse relationship noted between the rate of change in wages, or prices, and unemployment. Economists are trying to improve their understanding of the trade-off between inflation and unemployment so that Government policies can be fashioned to obtain a more favorable long-term relationship, or even decrease unemployment and inflation at the same time.

Improved evaluation of experimental programs is a significant aspect of methodological advances. In the case of the Head Start Program, the Office of Economic Opportunity had supported a large-scale evaluation study by Westinghouse and Ohio State University. Later studies supported by NSF indicate that this evaluation inadvertently used methods containing biases in the direction of making Head Start look useless or even harmful. The Westinghouse-Ohio State University evaluation was most influential in determining the character of Head Start, thus demonstrating the importance of developing a better methodology for evaluations in innovative social programs.

Another area which is receiving special attention is fundamental research in "social indicators." These indicators are data series that allow comparisons of socially important conditions and identification of long-term trends. Although the underlying work has been a part of social science concerns for several years, there is new emphasis on the identification of critical series. A landmark volume on social indicators has been published by the American Academy of Political and Social Science in its series known as *The Annals.* More than half the studies featured in this volume credit NSF with support of research. These studies were also the prototype for many larger-scale, more systematic investigations currently planned. It is expected that this research will rely in part on special computer-readable printouts from resource data centers which can be useful both in connection with the collection of social indicator data and for other research purposes as well.



With NSF support, social scientists are also studying such diverse problems as the reaction to industrialization of contemporary groups in different parts of the world, factors affecting the balance of payments in international trade, crime, and how real estate values are affected in changing neighborhoods.

The results of these and other investigations in the social sciences are expected to be useful in many ways, but two cautions need to be stated. First, social behavior is extremely complex, and spectacular breakthroughs for the solution of critical social problems are unlikely. Instead, it is more reasonable to expect a steady, incremental growth in techniques and methodology. This growth, even when impressive achievements occur, leads to the second caution. The contribution of the social scientist is to provide individuals and political groups with new options and help them to know the probable consequences of choosing any of these options. Science can raise the level of general knowledge in our society and make social processes and interactions more understandable, but it does not, of course, eliminate the need for personal choice and group decision-making.

The Persistence of Poverty

The way poor people's incomes respond to changes in the general economy is of critical importance in formulating programs to deal with problems of poverty. John McCall of the University of California at Los Angeles is trying to measure this income mobility with the use of economic models of the incidence, persistence, and control of poverty—

with special emphasis on those who stay poor and those whose incomes rise above a particular income level. In theory, the length of time in poverty or non-poverty should have an important influence on the probability of moving to poverty or non-poverty during the subsequent period. Dr. McCall is using a data file (the Social Security Continuous Work History Sample) that consists of information on race, age, sex, location, industrial affiliation, and estimated annual earnings for nearly one million anonymous individuals for the years 1957–66.

Several important, though still tentative, conclusions may be drawn from his preliminary results. The first is that a significant proportion of individuals remained in poverty throughout a 4-year period of substantial growth, even using the lowest of the three poverty lines considered (i.e., $1,500 instead of $3,000 or $4,500). This tends to substantiate the "backwash thesis" which states that certain subgroups in poverty are so isolated from society that they are unaffected by economic growth. If so, sustained economic growth may not be sufficient for the elimination of low earnings, and other policies, perhaps investments in human capital, such as health and training programs or income maintenance, may be needed.

The probability of remaining in a low-earnings category all 10 years, given low earnings in 1957, was significantly larger for non-white males than for white males. This was true for all age groups and all three poverty levels. For a $3,000 poverty line, the probability of a non-white male between the ages of 25 and 34 remaining in poverty for the entire 4-year economic growth period was 0.20; for a white male in the same age group it was 0.05. It would appear that to raise the non-white male's economic level will require much more intensive programs than generally stimulating the growth of the whole economy. However, Dr. McCall's evidence does indicate that in a buoyant economy, among those who *can* move across the poverty line, non-whites make greater gains than whites.

Stayer proportions (Dr. McCall's term for individuals who remain in their starting income category) proved to be very similar for non-white males and white females, while non-white females had the highest stayer proportions. For example, with a $3,000 poverty line, the probability of a non-white female between the ages of 25 and 34 remaining in poverty for the 4-year growth period was 0.27; for corresponding white females it was 0.16.

The most obvious explanation for the inferior economic performance of females is job market discrimination. In addition, because of their role in our society, many of the skills developed by females either are not or cannot be converted into their income equivalents. Also, since female participation in the labor force is less stable than that of males, employers are less willing to invest in female human capital, which further lowers their productivity and wages relative to males. All the differences Dr. McCall observed between white and non-white females were much less than the correspond- differences for males.

The Use of Violence

One out of every five American men questioned in a nationwide survey said he believed some degree of violence was necessary to produce needed social change in this country. An even larger proportion, nearly one third, were willing to tolerate substantial police force, including shooting to kill, to control student or black uprising.

The questionnaires were administered in 1969 by a research team headed by Monica Blumenthal from the University of Michigan. The sample of 1,374 was selected to represent all men in the United States between the ages of 16 and 54 and to represent all races, regions, economic classes, and social statuses.

The research was particularly concerned with two types of violence: that used for social control (force or shooting by police) and that involved in social change (such as that occurring in ghetto disturbances or during protests). The study began by asking the men to name the things going on within the country that worried them. Some 65 percent cited activities of violence, usually civil disturbances and political protests. Only 25 percent mentioned traditional forms of crime. Although most agreed that violence has its roots in social problems, many looked to punitive legislation and bolstered police forces as means of prevention. For example, 61 percent said that in ghetto riots, police should shoot but not to kill, while 30 percent felt that police should shoot to kill at least sometimes. When asked whether it was justified to kill another person, 89 percent answered that it was permissible in self-defense, 93 percent said it was right in defense of one's family, and 58 percent said it was right in defense of one's own house. This, the researchers felt, was consistent with the traditional male role in America.

If a person considered a certain act to be violent, the study finds that he was likely to condone substantial police force to control it. However, he did not consider the use of force by police to constitute violence in these cases. For example, while 85 percent thought looting to be violent, only 35 percent considered the police shooting of looters to be violent.

Dr. Blumenthal compared those men who favored strong police action in cases of civil disturbances with the smaller grouping who believed at least some violence was necessary to bring about improvement in society in a reasonable time. Those who favored violence for social control tended to be older, less well educated, and white. More important factors differentiating the

two categories were found to be attitudes toward the persons exercising the violence. Those who rate students or blacks as untrustworthy tend to condone police violence, while those who see the police as untrustworthy tend to condone violence on the part of blacks and students.

These results, based on a study of men only, are the first to come out of a series of studies that will also explore the attitudes of women.

High School Athletics and Social Mobility

One of the arguments often advanced on behalf of extracurricular athletic programs is that they encourage upward social mobility. Unfortunately, much of the discussion hinges on anecdotal information. Now, Richard Rehberg of the State University of New York-Binghamton is systematically studying the social mobility of successful athletes over time as compared to nonathletes. The data consist of questionnaire responses of 1,208 10th-grade boys from various school systems in the southern region of New York State.

Although athletic participation might facilitate upward mobility in different ways, the researchers chose to study a mechanism that is very important at the high school level—the relationship between sports and the enhancement of educational attainment. Better grades, graduation from high school, and attendance in college served as indicators of this process.

Dr. Rehberg found that high school senior athletes had higher expectations for attending college than comparable nonathletes. This raised the question of what intervened between athletic participation and that college expectation. Further investigation suggested that the visibility of athletes increases the attention they receive from school personnel, especially in regard to career counseling and encouragement. School staffs are likely to give more status to the athlete. This might lead to higher expectations for current and future achievement and greater encouragement in areas other than sports, such as in academics and attending college.

Realizing that a certain amount of such expectation and encouragement occurs in the home and is related to a family's socioeconomic status, the researchers investigated the relationship between athletic performance and educational aspirations within each economic class. For each class, the athletes showed higher aspirations than the nonathletes, but the differences were greatest among boys from low status-income homes who received little parental encouragement, and who had accumulated low grades.

Dr. Rehberg concludes that the apparent gains from participating in athletics are greatest among those students less disposed by other factors toward educational attainment. Apparently, success in sports affects expectations and behavior of teachers and school officials, which may be particularly significant for the careers and life chances of student athletes in the lower socioeconomic levels.

This study illustrates an important part of research in the social sciences, a part that can be called the evaluation of conventional wisdom. The fact that findings of an individual research project may seem obvious—as perhaps they do in this case of upward mobility for athletes—masks the fact that conventional wisdom commonly accommodates individually reasonable but conflicting conclusions from the same premises. Social science refines what we know, identifies the significant mechanisms that control social processes, and develops a more rigorous causal pattern that goes beyond common lore.