be drawn." He added, "Under the pressure for immediate results, and unless deliberate policies are set up to guard against this, applied research invariably drives out *pure*."

I feel confident Bush would agree that a 25-year tradition of primary devotion to uncommitted research is an adequate guarantee that Research Applied to National Needs will not drive out "pure" research from the Foundation. I am sure that Bush, an engineer, would approve what James Fisk said in his memorable address at the centennial of the National Academy of Sciences (*3*):

Far from interfering with "science for its own sake," the applications of science seem steadily to be leading us into realms of greater and greater intellectual and even spiritual challenge. . . . Applied science and technology show directions in which pure scholars may couple to any degree they choose with the human issues and problems of their time. This, too, is not a bad thing for the motivation of men, or for smoothing the path between the ivory tower and public plaza.

No account of the origins and aspirations of the National Science Foundation, no matter how brief, would deserve reading if it did not allude to the unique role, extraordinary competence, and ceaseless devotion of Alan Waterman. President Truman voiced his esteem and gratitude; it was shared by all who knew Alan. I, who was with him for 14 years while chairman of the board and the executive committee, have especial reason for admiration and affection. Under his leadership the staff and the board of the Foundation became each and together bands of friends working for mutual objectives. "What, after all, is an organization?" asked Vannevar Bush. "It is merely the formalization of a set of human relations among men with a common objective. The form of organization is important. Far more important are the men themselves, and their insistence on working together effectively for a common end." The National Science Foundation is such an organization.

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A Foundation for Research

The return on investment in scientific research during the first 25 years of support by NSF is discussed.

William A. Fowler

Twenty-five years ago the challenge was direct and explicit. The National Science Foundation Act of 1950 authorized and directed the Foundation "To initiate and support basic scientific research. . . ." There were additional mandates; but there it was, the American people, through their elected representatives, created *A Foundation for Research,* and that is the title of this piece. It is not *the* foundation; there are many other agencies and institutions in and out of government which support research. The word "foundation" is not used solely in terms of funding but more in its literal sense, the underlying structure on which all else rests. The word "research" is not qualified by the adjective "basic" because in response to the pressures of our time, the Foundation was authorized to support applied research in 1968 by amendment of the enabling act of 1950.

One hundred and one years ago in *Life on the Mississippi* Mark Twain wrote: "There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact." Those in experimental work may relish Twain's jibe, those in theory may resent it. Be that as it may, the answer to Twain is clear: Research is the investment of fact, the investment which may lead, at first to healthy conjecture and speculation, but which ultimately leads to understanding and to wisdom.

The NSF has supported, encouraged, initiated, and counseled a fair share of the research investment in this country over the last 25 years in its many functions as *A Foundation for Research.* The NSF has other functions, but here it seems appropriate to inquire into what return, not of conjecture but of knowledge, has this investment brought. This will be the burden of this tale. The choice of research returns to be discussed will be arbitrary but, it is hoped, not capricious. The main subjects will be earth science, molecular science, environmental science, astronomical science, and social and applied science. The word *science* is used here because each of these subjects has involved a number of scientific disciplines. For example, molecular science includes molecular biology, molecular chemistry, and molecular physics. Astronomical science includes astronomy, astrophysics, and astrochemistry. The mathematician will wonder why *The Discovery of New Sporadic Sample Groups* or *The Logic of Computers* was not discussed, as well they might have been. The physicist will wonder why *Parity Violation in the Weak Interaction* or *The Laser Renaissance in Optics* was not included; the chemist, why *Macromolecules in Plastics and Polymers* was omitted. Nonetheless the mathematician, the physicist, and the chemist will find his branch of science thoroughly involved. This piece is about the woods, not about the trees. It adheres to these prescient words and I quote:

The complete solution of many research problems today requires the correlation of many individual viewpoints approaching the problem from several directions. The Foundation is acutely aware of its obligation to support integrated attacks upon borderline and interdisciplinary problems.

The author is Institute Professor of Physics, California Institute of Technology, Pasadena 91125. This article is the text of an address delivered on 21 April 1975 at a National Academy of Sciences symposium commemorating the 25th anniversary of the National Science Foundation.

No, those words are not from yesterdays' news release. They are from *The Second Annual Report of the National Science Foundation* for 1952.

In telling this story it will be the whole story (within one man's limitations) and not just the NSF role; but some bias will be apparent. In telling this story, there will be no mention of the names of individual investigators. On this day it would be more appropriate to name the program managers who choose the investigators. Anyhow as Seneca said, "The reward for a good deed is to have done it." There will be no attempt to parcel out credit here and there—this tale of research in the last 25 years will probably fail in some ways to do justice to history, but credit and blame alike will be anonymous. There will be no elaboration, beyond this brief mention, of the role of undergraduate, graduate, and postdoctoral research in the training and education of budding scientists.

Earth Science

Where better to begin than here at home on the spaceship which we call Earth. It is, indeed, our spaceship and it is the only possible habitat in the foreseeable future for the billions of human beings who ride it. Thus we must learn all we can about it, if we are to conserve and utilize its resources for the benefit and survival of man.

During the lifetime of the National Science Foundation, the earth sciences have been revitalized by one of the most rapid, thorough, and potentially practical revolutions in the history of science. Cliché or not, it has been a truly fascinating development. Instead of the fixed object which the earth appears to be, to one man during his lifetime, the earth has been shown to be an intricate mechanism with interlocking movements on a global scale which involve its surface and extend deep into the interior. This big picture which goes under the name of continental drift, sea-floor spreading, and plate or global tectonics was put together from many sources, but a prolific one among these was the data gathered about the sea floor during the hundreds of seagoing expeditions sponsored by the Foundation. The Deep Sea Drilling Project, using the drilling vessel *Glomar Challenger* under NSF auspices, brought to onshore laboratories oceanic sediment cores that verified and elaborated the new ideas.

For many years the concept of continental drift was an intriguing but controversial one. It did not gain wide acceptance because of many apparent discrepancies in the evidence and because of the lack of a reasonable driving mechanism. It all started with the fit of continental margins, especially the west coast of South Africa and the east coast of South America; but by now a number of other pieces of evidence have been brought to light.

1) *The matching of rocks between continents.* Detailed studies in northeastern Brazil and west Central Africa have shown that the older rocks in both continents are similar in composition, age, and structure. Similar structures that appear once to have been continuous have now also been identified in southern South America, Australia, and Antarctica.

2) *Fossils.* The finding of fossils of shallow water reptiles and amphibians in rocks more than 200 million years old in all of the southern continents, including Antarctica, argues strongly that these continents were once joined together. There is no other logical way for these animals to have spread from one continent to another.

3) *Rock magnetism.* The earth's magnetic field periodically reverses, and on land a sequence of chronology of these reversals had been established for the past 6 million or 7 million years. About 15 years ago it was noted that the mid-Atlantic Ridge is flanked by magnetic anomalies that are parallel to the ridge, and symmetrical on either side. The pattern of anomalies on the west side of the ridge is virtually a mirror image of the pattern on the east side. These anomalies are apparently also caused by the reversals of the earth's field. Molten rock rises from the mantle along the mid-ocean ridges, cools, and acquires the imprint of the magnetic field at the time of cooling. More molten material forces the cooled material to one side and literally pushes the sea floor apart. As the sea floor spreads, the continents are carried along on plates in the earth's crust. Whether these plates are pushed by the outward motion of the sea floor from the mid-ocean ridges or pulled by downgoing slabs at the continental edges or dragged by convective currents in the mantle is still not perfectly understood.

4) *Seismology, the study of earthquakes.* The earthquakes of the world are concentrated in belts or bands. These belts follow the mid-ocean ridges, the margins of some continents, and the deep trenches of the oceans. Detailed studies of the oceanic trenches, especially the Tonga Trench in the Pacific, show that the depth of earthquakes gets progressively greater as the trench is approached, reaching down to 700 kilometers. This suggests that, as the crustal plates move away from the ocean ridges, they are also drawn down underneath the margins of the continents or in the deep trenches of the oceans and reabsorbed into the mantle.

5) *The results of the Deep Sea Drilling Project.* If the magnetic stratigraphy and the concept of plate tectonics are correct, there should be no part of the oceanic crust that is more than about 200 million years old, and this part of the crust should be close to the continents and the trenches. Drilling across the mid-Atlantic Ridge and in the Pacific has confirmed this. For example, the volcanic basement close to the mid-Atlantic Ridge is only a few million years old, but close to the eastern margin of the United States, for example, the volcanic rocks of the oceanic crust are about 160 million years old.

This new unifying concept of global structure and tectonic processes provides a framework for new thinking and research into the mechanisms that shape the earth. The discovery of the earth's free oscillations in the early 1960's and their use to infer the deep structure of the earth has been woven into this framework. This discovery revealed in more detail than heretofore that there exists a partially molten zone beneath the crustal plates and that the movement of material within this zone must play a key role in driving the plates.

Within this framework has arisen a deep understanding of earthquake phenomena which is of the greatest practical importance. First of all, the concentration of seismicity at the boundaries between plates explains the global pattern. There is much more in addition. By combining laboratory experiments on the fracture of rocks with field data, earthquake faults can be described in terms of empirical fracture mechanics, and the radiation pattern of seismic waves can be predicted theoretically. Precursory phenomena prior to earthquakes have been detected, and respectable seismologists around the world have now joined astrologers, mystics, and religious zealots in earthquake prediction. Put your bets on the seismologists; they may bring home a windfall of untold benefit to human society within the next decade.

Many problems remain in the earth sciences. The details of the crustal driving mechanism are still obscure. Evidence that the crustal plates are being pulled not pushed apart comes from the myriads of cracks and fissures in the ocean floor investigated by the deep sea research submersible, the R.V. *Alvin*, and its French counterparts. Much is still to be learned about vertical as contrasted to horizontal movements of the earth's crust. The Foundation has supplied instruments and ships and other facilities in the past; it will continue to do so in the future of this exciting and dynamic field. Coming up is the International Phase of Ocean Drilling (IPOD) which will carry out deep sampling of the oceanic basement below the overlying sediments. More will be learned about the potentially rich deposits of iron, manganese, copper, and chromium, which are thought to reside on and in the ocean floor. Eventually the Mohole dream may come true, and drills will puncture the earth's crust, reaching into the mantle itself.

The earth of ours is not all land and sea; it has an atmosphere which supplies the breath of life and shields us from the dangerous portions of the sun's spectrum and from the direct action of solar and cosmic high energy particles. Atmospheric science includes research on phenomena in the lower atmosphere where most weather, climate, and pollution effects are determined, in the middle atmosphere where incoming solar energy is directly absorbed and complex physical and chemical interactions occur, and in the high atmosphere where interactions with the solar wind and with solar outbursts of x-rays, ultraviolet light, and penetrating particles are paramount. An important factor in the forward thrust of atmospheric research was the creation in 1960 of NCAR, the National Center for Atmospheric Research. NCAR studies everything from raindrops and hail in the atmosphere to spots on the sun, in a wide-ranging research program. It provides balloon, aviation, and computing facilities for scientists throughout the country.

The United States has committed itself to support of GARP, the Global Atmospheric Research Program. The NSF's commitment has been to stimulate and intensify research in large-scale atmospheric circulation patterns designed to achieve a capability in long-range weather prediction. In the summer of 1974, one of the largest and most complex international scientific experiments ever undertaken was carried out under GATE, the GARP Atlantic Tropical Experiment.

The tropics are unique, for it is there that most of the heat received from the sun is stored in the oceans. The absorbed solar energy is transferred into the lowest layers of the atmosphere as latent heat in water vapor evaporated from the oceans. Within this atmospheric boundary layer, the latent heat is realized as sensible heat, principally through sporadic cumulus cloud development. The clouds subsequently become organized as parts of larger scale systems, thereby distributing this energy into the middle latitudes. The study and understanding of these complex processes is the principal aim of GATE.

Analysis and interpretation of GATE data will continue for many years. The largest share of that responsibility in the United States will be assumed by the academic community. The NSF is committed to ensuring that this culminating phase is successfully accomplished.

Molecular Science

Three billion years ago our mother earth gave birth to life in its simplest form, a molecule that could replicate itself by using building blocks formed by random photochemistry in some aboriginal soup. Within the last million years or so those simple molecules have organized to form a living organism that can understand the molecules themselves and how the molecules build one gene, the unit of heredity, the key to replication and reproduction. This miracle of understanding has come into being over the last hundred years or so, but it is research in the last 25 years which has brought forth a dramatic and coherent picture of the fine structure of the gene, the genetic code, and the control of gene expression. A great synthesis of knowledge has resulted which has conceptually bridged the long-mysterious gulf between the world of the living and the nonliving. This synthesis has led to realization of the continuity between inanimate and animate matter, based on the understanding of the potential for life, inherent in molecular organization.

Developments in molecular biology have been international in origin, and in the United States there has been a number of supporting agencies. Many critical advances were made by NSF grantees. In retrospect it is fitting that the first NSF award, grant G-1, "The Effect of Hormones of the Anterior Pituitary Gland on Fatty Acid Metabolism," was in biology. The story of the double helix model for DNA, the genetic material, was already known, in the infancy of the Foundation, and it was also known that genes are arranged linearly on the chromosome. Early work supported by the NSF provided the first proof that mutations within a gene also form a linear array, and that mutations probably involved a single DNA nucleotide. This work laid the basis in part for the further development of molecular genetics.

In another grant program, the building blocks of DNA were put together into a predetermined sequence of groups of three, each of which is a code word. This collection of synthetic genes was then used to make a second molecule called messenger RNA, which, in turn, directs the synthesis of a proteinlike chain. This new chain was then broken down into its individual building blocks, one by one, and each was identified. By identifying each of the building blocks of the new protein, it was possible to break the code of the original DNA and confirm that three nucleotides make one code word and specify a particular amino acid. It was also possible to establish the direction in which information of the messenger RNA is read, that punctuation between code words is unnecessary, and that code words cannot overlap. How is a particular amino acid positioned properly in the chain? The middleman in this process has been identified as another kind of nucleic acid, transfer RNA. There are different species of transfer RNA, each of which can recognize only one amino acid and a proper code word on messenger RNA. The primary structure of transfer RNA was determined by investigators working on an NSF-supported grant. Other work led to the realization that not all cells read a genetic message in exactly the same way and thence to the identification of the *stop* signals, which mark the spot at which synthesis of proteins stops.

The NSF also supported some of

the work which led to the operon theory of gene control, that is, the existence of operator segments of the chromosome which determines whether a certain group of genes will be expressed. Later work suggested that the products of regulatory genes are proteins that bind to operator regions of DNA and thus determine whether particular genetic information is expressed. The first two regulatory proteins were isolated with NSF support.

Environmental Sciences

The NSF has played the leading role in initiating comprehensive studies of extensive ecosystems. Although one view of ecology has always been synthetic and holistic, it was apparent in the early 1960's that most studies were not sufficiently comprehensive and quantitative to achieve more than a generally descriptive level. After years of modest support of systematic biology, NSF took a major initiative in supporting the Biome Programs generated under the International Biological Program. The investment in systematic biology began to pay off.

While it cannot be said that the attempt to construct a total system model has been successful, there has been considerable success in modeling component parts. In addition, the elements required for describing and understanding these systems have become much more sharply defined. Initial emphasis has been primarily on energy (or carbon) flow, water flow, and nutrient flow. The requirement for completely balancing these has forced attention to elements that had been largely ignored in the past: the importance of below-ground processes, and the large role played by decomposers as compared with grazers. In both forests and grasslands, more than half of the energy flow from photosynthesis is used below ground in root systems. The importance of roots is no surprise, but the magnitude of the energy flow to support the system has been, and it is now clear that total system models will require much more attention to below-ground processes than would have been suspected.

In a similar way, there had been a rather general expectation that a substantial part of the carbon captured by plants was subsequently consumed by insects and grazing animals. These "consumers" turn out to be quantitatively a rather minor factor, and the major pathway for processing the carbon input is through "decomposers." Since the flow of nutrients is closely related to the flow of carbon, the functioning of the decomposer system is critical in returning nutrients to the soil and making them available for new plant growth.

The models developed in these studies have found surprisingly early application to a variety of land management problems, simply because they are the first tools available for making reasonable projections of the consequences of management alternatives. Most important, however, it is clear that a new era has been initiated in which ecology will be more adventurous, more quantitative, and will direct more attention to the construction of models for understanding and predicting the behavior of total systems.

Our immediate environment is the land, the sea, and the air; but the deep core of the earth produces a magnetic field around us which deflects penetrating particles from the far reaches of the galaxy. Our environment is the Universe. One of the most important trends during the life of the NSF has been the developing recognition, shared by scientists and the general public alike, that the environment is in fact a single entity, a gigantic system. Environmental science is the study of all natural processes, their interactions with each other and with man. The National Science Board and the staff of the Foundation have been well aware of the many important problems such as the removal of sulfur from smoke, the recycling of industrial wastes, and the protection of open spaces and of the technological and institutional changes needed to change them, but they have also been greatly concerned about the advances required in the science of environmental systems if the basic knowledge and understanding needed to help resolve problems of public interest are to be provided.

Astronomical Science

And now we lift our eyes from the earth to the heavens—to the planets, the sun, the stars and the interstellar medium surrounding them, the galaxies, and the vast reaches of space and time. It goes without saying that in astronomical science in the past 25 years it has been the space adventure from Sputnik to Apollo that has captured the popular fancy. It goes without saying, too, that the National Aeronautics and Space Administration (NASA) has played the primary role in this incredible human venture. At the same time NSF has played a supporting role. For example, NSF funds built the mass spectrometer, LUNATIC 1, used in the strontium-rubidium dating of lunar rocks and soils which showed that the moon and the meteorites and inferentially the earth and the sun were the same age, approximately 4½ billion years old. We do not know how the solar system started but we jolly well know when!

Over this same period there has been a veritable explosion in astronomical science, and here NSF has played an important and in many way the leading role. Visual astronomy is thousands of years old, and optical astronomy is 366 years old. Radio astronomy is 44 years old but it has only been in the last 25 years that radio astronomy has become a mature science. Witness the development of very long baseline interferometry, which gives us exquisite small details of the structure of enormous radio sources. Here NSF has played a major role. This same 25 years has witnessed full-scale extension of optical astronomy into the infrared and ultraviolet and the birth of microwave and molecular astronomy, x-ray astronomy, gamma-ray astronomy, and neutrino astronomy. In addition, cosmic-ray studies, no longer in the forefront of elementary particle physics, have become an integral and important part of astronomical science. We can now "listen" to the "music" of the spheres over many octaves and not just within one. The celestial message is borne not only by photons, but also by neutrinos and by energetic nucleons and nuclei.

In order to observe and detect over a wide range of radiation and particle energies, it is necessary to have observatories equipped with large telescopes or other detectors and sophisticated auxiliary instrumentation. Very early in the life of the Foundation it became clear that national centers of research were necessary to meet national needs for research in astronomy and the atmospheric sciences requiring facilities, equipment, staffing, and operational support that are beyond the capabilities of private or state institutions and that could not appropriately be provided to a single institution to the exclusion of others. Unlike many federally sponsored research laboratories, the NSF-supported National Research Centers do not perform specific research tasks assigned by or for the direct benefit of the government. They are maintained for the purpose of making available, to all qualified scientists including their own staffs, the facilities, equipment, skilled personnel, support, and other resources required for the performance of independent research of the scientists' own choosing. This has all run parallel to NSF support of so-called users' groups at the national accelerator centers built by the Atomic Energy Commission.

The Foundation supports four astronomy centers [National Astronomy and Ionosphere Center at Arecibo, Puerto Rico; Cerro Tololo Inter-American Observatory near Santiago, Chile; Kitt Peak National Observatory at Tucson, Arizona; and National Radio Astronomy Observatory (NRAO) at Green Bank, West Virginia] and one atmospheric research center (National Center for Atmospheric Research at Boulder, Colorado).

At the same time, the Foundation has provided an increasing amount of research project and instrumentation support for ground-based astronomy in universities and other private institutions, both national and international. New, up-to-date instrumentation is essential in research activities in all fields. Here the term ground-based must not be taken too literally. For example, the stratoscope balloon-borne telescope project, with NSF support, obtained pictures of planets and galaxies at the high resolution of one-tenth of an arc-second. Grantees of NSF have sent their instruments far and away in rockets and satellites. Today the NSF supplies more than half of the total federal support of research in astronomy.

As was mentioned above, there is no point in parceling out credit here and there. Rather, it is the overall picture to which NSF has contributed its fair share, which merits our attention; and what a picture it is. Our view of the Universe has widened and deepened with astronomical discovery after discovery in the past quarter of a century. First of all consider the secrets wrung from observations of the interstellar clouds of gas and dust that permeate our galaxy. In 1951 came the discovery of the 21-centimeter line of neutral hydrogen, in 1963 the hydroxyl radical was observed, and in 1968–1969 the molecules of ammonia and water. Astrochemistry came into being. Approximately 150 lines from 33 different molecules, some with rare isotopes, have now been observed; 27 of these were first detected by NRAO telescopes. I'm glad to note that ethyl alcohol has finally been observed—I was beginning to wonder whether Heaven was such a great place after all. But in all seriousness, the interstellar medium is of the utmost importance to us not only because it is the site of the formation of stars like our sun, but also because it contains the simpler organic molecules whose further buildup on planets may lead eventually to the development of life. Are other galaxies seeded with the building blocks of living organisms, and does this mean that other civilizations share the Universe with us? Perhaps the newly resurfaced 1000-foot dish at Arecibo will in time receive a return message to the one it sent out at its rededication last 16 November (1974). The optimists believe the primary problem is whether the Arecibo dish will last long enough. After all, the light travel times out and back are calculated to be at least tens of thousands of years at best.

As one turns to luminous objects, the list of surprises goes on with the discovery of the galactic x-ray source in Scorpius in 1960, the discovery of quasars in 1963, and the discovery of pulsars in 1967. Quasars represent the violent transformation of as much as 1 million solar rest masses into energy in the form of magnetic fields and relativistic electrons. Is it annihilation energy, nuclear energy, gravitational energy? We still do not know, and I for one believe that the solution of this celestial energy crisis, when it comes, will tell us something about energy generation and energy transformation of potential application to our terrestrial energy problems.

Quasars have been observed with exceedingly large red shifts, now up to slightly over 3.5. The two objects with the largest red shifts were first identified in a survey conducted with NSF support. If these red shifts arise from the expansion of the Universe, as most astronomers and cosmologists believe, then we are seeing out to distances comparable to the radius of the Universe and back to times comparable to the age of the Universe. If the quasars are closer, as others argue, then their large red shifts arise from some very exotic physics. The controversy about the origin of quasar red shifts is still very much alive, but it is the observations themselves that are the most intriguing. The wavelengths observed are four-and-one-half times as long as those of the corresponding laboratory wavelengths, and the observed frequency is only 22 percent of the laboratory frequency. Identification of spectral lines over this range is one of the triumphs of modern astronomy, and it would not have been possible without the development of sophisticated auxiliary electronic instrumentation for optical telescopes. Kitt Peak and NSF grantees at other observatories have played a major role in these developments.

The discovery of pulsars, and particularly of the Crab pulsar, confirmed the 41-year-old prediction that neutron stars should result from supernovae explosions. But who would have guessed that rotating neutron stars would somehow produce narrow beams of radio emission that were first mistaken for pulses and whose origin we still do not basically understand. Nature trumps the best card in our hand and our best science fiction tells a poor story by comparison. Neutron stars are such precise clocks that, with the recent discovery at Arecibo of a pulsar with a binary companion, it may soon be possible to find out whether Einstein was really right about gravitational red shifts and the relativistic advance of periastron. Neutron stars represent an extreme system for the nuclear and elementary particle physicist and at the same time for the solid state and plasma physicist.

The general relativist more or less takes these neutron stars in his stride—he knew they were there all the time and anyhow he is now on the trail of Einstein's ultimate singularity—the black hole. Really he is watching the x-ray and radio and optical astronomers who may have found a black hole in Cygnus X-1 accreting material from its optical companion with the accreting material radiating x-rays just before it plunges to its ultimate doom in the black hole itself. Most x-ray sources are probably much less exotic but, if only one contains a black hole, these sources will outrival quasars and pulsars in the minds of Einstein's legions of admirers. Black holes are the ultimate in compact objects—the end of the line in stellar evolution; stars that have collapsed to their event horizons and were once thought not to emit radiation or particles and to absorb everything that falls on them. But within the last year we have been told that black holes may not be all that black if quantum effects are taken into account. The strong gravitational fields around a star approaching its event horizon produce pairs of particles and antiparticles which carry away energy, and the black hole evaporates its mass. If it is a small enough black hole, it evaporates completely. It all sounds preposterous, but if it leads to the unification of general relativity and quantum mechanics then the last of the years we are celebrating will turn out to be the most significant of them all.

Quasars, pulsars, neutron stars, black holes—what more surprises could there be? And yet in some ways the discovery of those objects was eclipsed with the discovery of the microwave background radiation in 1965. This radiation is very precisely the same no matter in what direction the big horn detectors are turned; it is apparently universal, and its spectrum is quite closely that of a black body.

For most astronomers it is the relict of the primordial fireball of the "big bang," which marked the beginning of the expansion of the Universe, and for many it is the best evidence for that expansion. This new evidence for the "big bang" stimulated a renewed investigation of nucleosynthesis in the fireball—but to no avail. There are no known stable nuclei at mass 5 and mass 8 in the hierarchy of nuclear masses, starting with the proton and neutron at mass 1. These mass gaps prevent nucleosynthesis beyond helium at mass 4 under the conditions in the "big-bang" fireball. Deuterium with mass 2, light helium with mass 3, and ordinary helium with mass 4 can be made, but only in an "open" universe that will expand forever; it cannot be made in a "closed" universe that will stop expanding in time and eventually contract back to a singularity. Astronomical evidence, such as it is, favors the idea of an "open" universe and the existence of deuterium; helium 3 as well as helium 4 follows straightforwardly from "big-bang" synthesis under the simplest assumptions possible, a homogeneous, isotropic expanding Universe with almost zero baryon and lepton numbers.

These exciting observational discoveries tend to overshadow the advances simultaneously made in our understanding of stellar evolution and of the nuclear processes associated with the various stages of that evolution. The realization in the period 1952 to 1955 that the red giant stage of stellar evolution involved helium burning which transforms helium into carbon and oxygen was just as far-reaching as the discovery in 1920 that the main sequence stage involves the conversion of hydrogen into helium. This understanding of the red giants led to the prediction of the properties and almost the exact energy of an excited state in the carbon-12 nucleus. This state was subsequently found, and we now know that it determines the roughly one-to-one ratio of carbon to oxygen that exists in the universe and on which all life, including ours, so critically depends. Without the resonance in the first stage of helium burning provided by this state, the final result of the burning would be all oxygen; there would be no carbon from which to construct amino acids and proteins, and where would we be? Moreover this fundamental understanding of the red giants has been followed by deeper appreciation of what occurs in the advanced stages of stellar evolution—in the variable stars, in the so-called horizontal branch, in the red super giants, in the blue super giants, in novae and planetary nebulae, and in supernovae. The answers are not all in yet, but the conceptual framework is there.

Stellar evolution implies nuclear transformations from element to element. In these 25 years, it has become clear that the elements beyond helium can be produced in stars and ejected by stellar explosions, such as supernovae, into the interstellar medium. From this medium, later generation stars are formed as well as their planets. This includes the inhabitants of one of the planets of at least one of these stars. In 1956 the abundance of the elements in the solar system was put into reasonable order, and in 1957 a reasonable explanation of that order was given in terms of nucleosynthesis in stars, which follows inexorably from energy generation in these celestial objects. There is one large fly in the ointment. The very beginning is the conversion of hydrogen into helium in main sequence stars, including the sun. The nuclear physics of the conversion tells us that neutrinos should be produced, and the physics of neutrinos tells us they should traverse the sun with practically no absorption and should reach the earth with the speed of light. Alas, diligent searches have not detected these neutrinos, and something is rotten elsewhere than Denmark. What can the matter be? Who will set us right on this one? May he or she mercifully appear soon!

The rapid experimental and observational advances have not been completely assimilated theoretically. Some think there exists a crucial situation in our understanding of the physical universe, and I cannot refrain from telling a story if only to put my "gee whiz" attitude about astronomy in perspective. A friend of mine, who shall be nameless, takes it all very seriously and some time ago, working under an NSF grant, he wrote a paper entitled "The Developing Crisis in Astronomy." Sure enough, when the paper was published there was the telltale asterisk after the title referring to a footnote which read, "Supported in part by the National Science Foundation." Well, you can't win 'em all.

Social Science and Applied Science

In an entirely different context, in the story of the death of a young President, who earlier graced this Academy's centennial ceremonies, William Manchester wrote, "Research, of course, is no substitute for wisdom." The "of course" is quite right. But let there be no misunderstanding. If we are to avoid the destruction of nature and the degradation of mankind *we must learn how to transform research into wisdom.* Social science and applied science in different ways strive toward this goal.

Social science was not included in the mandatory language of the NSF Act in 1950, but research in the social sciences has been assisted since late 1953, beginning with subareas close to the mathematical, physical, and biological programs. The close bonds between the social and natural sciences have been since then one of the hallmarks of NSF activities. One comment must suffice. The NSF's stimulation of research in economic theory, econometrics, and social indicators, including related work in sociology and social psychology, over the years provides a good part of the base upon which energy policies will be erected in these times of energy crisis.

Engineering science has been part of the NSF program from the beginning.

Engineering science has aimed to increase the understanding of the principles and concepts that are common to and underlie a wide variety of technological problems. It supported the finite element method in structural engineering and, across the board, it supported research on tungsten carbide as a substitute catalyst for platinum. In the mid-1960's it initiated a concerted research effort to apply systems analysis and operations research to the efficient allocation of urban police forces. This work led to the development of a general methodology for the dispatching and deployment of police patrol forces and for evaluating the consequences of technological and administrative innovations. There are immediate applications to fire and emergency ambulance services.

Materials research has been an NSF function since the beginning, and the program was considerably augmented when the Foundation assumed the responsibilities for the interdisciplinary Materials Research Laboratories from the Department of Defense in 1971. Fundamental observations have been supported on the quantized nature of magnetic flux surrounded by a superconducting ring. These observations led in part to the development of superconducting interference devices, which have become of considerable technological importance. In another area, developments point toward high strength polymers which may possess an electric modulus as high as that of steel and a greater tensile strength, while at the same time weighing less than 20 percent as much as steel.

Thus a firm groundwork was laid in the social and applied sciences for the Research Applied to National Needs (RANN) program that was developed in response to the applied research authorization granted in the amended NSF Act of 1968. Interdisciplinary Research Relevant to Problems of Society (IRRPOS) was begun in 1969, and it was then only necessary to sharpen and focus research on selected environmental and social problems and on opportunities for future technological development in order to respond to the legitimate demands of a society for which the fruits of research had been, speaking without prejudice, a mixed blessing. Basic to the concept of RANN from the beginning was the eventual transfer of programs to mission-oriented agencies of the federal government and to industry. Again one example must suffice. Between 1971 and 1974, RANN led in the effort to define a solar energy research program to more fully understand and exploit this inexhaustible resource with which we are blessed. The payoff came with the formation of the Energy Research and Development Agency (ERDA) to which RANN was able to transfer funds, staff, and know-how. At the same time RANN was able to continue with concentration on innovative, long-range, high-risk, high-payoff projects in solar energy research. The NSF is indeed responding to national needs.

Conclusion

This has been one man's account of the return on the American people's investment in *A Foundation for Research*. There have been failures as well as triumphs, but those are for others to record. Research has enriched our lives and nurtured our livelihood but it has also brought inevitable problems which hopefully in these next years it can help to ameliorate. All in all it has been a 25-year success story with, best of all, rich promise for the future. We will fulfill that promise only if we succeed in *transforming research into wisdom in the compassionate use of knowledge in the affairs of mankind.*

Relevance of Demographic Transition Theory for Developing Countries

The theory offers only partial explanation of European trends and ambiguous advice for developing countries.

Michael S. Teitelbaum

The theory of the demographic transition is by now a well-known feature of discussions of human population phenomena, and recently it has also become an element of international politics. In the debates at the World Population Conference in Bucharest in 1974 the theory of the demographic transition was an active, if usually implicit, participant. It lay behind some of the most attractive and confident sentiments expressed ("Take care of the people and population will take care of itself," "Development is the best contraceptive"), and there is no reason to think that the proponents of these views believed they were espousing anything but the revealed wisdom of demographic science (*1*).

Yet popular adoption of a scientific theory usually lags far behind the elaboration of the theory itself. The theory of the demographic transition was originally developed nearly a half-century ago, and ironically its explanatory and predictive power has come into increasing scientific doubt at the very time that it is achieving its greatest acceptance by nonscientists. In scientific circles, only modest claims are now made for transition theory as an explanation of the very demographic experiences from which the theory was originally drawn —those of 19th-century Europe. When applied to the markedly different social and economic circumstances of modern-day Asia, Africa, and Latin America, the explanatory and predictive power of transition theory is open to further scientific questions.

Hence the credence given to assertions based upon transition theory that development will "take care of" population matters as it did in Europe justify an assessment of (i) what is known about what *did* happen in Europe and (ii) the extent to which the same processes may be expected in developing countries, given their similarities and dissimilarities from the countries of 19th-century Europe.