The Computer Science and Engineering Board

Organization

The Computer Science & Engineering Board was created in June, 1968 by the National Academy of Sciences in recognition of the need for a special body within the Academy to study the role of the computer in the economy and culture of the nation. The latest in a long line of distinguished groups organized by the Academy since its establishment by President Lincoln in 1863 to "foster the orderly development of science and its use for human welfare," the new Board takes its place among such effective academy organizations as the Materials Advisory Board, the Space Science Board, and the Committee on Science and Public Policy—to name just a few.

The Board is composed of outstanding experts in computer and information science drawn from both the academic and industrial communities.

CHAIRMAN
Anthony G. Oettinger
Professor of Linguistics and
Applied Mathematics
Aiken Computation Laboratory
Harvard University

VICE CHAIRMAN
John R. Pierce
Executive Director
Research Communications Sciences Division
Bell Telephone Laboratories, Inc.

Launor F. Carter
Vice President and General Manager
Public Systems Division
System Development Corporation
Santa Monica, Calif.

Wesley A. Clark
Research Professor of Computer Science
and Director of the Computer System Lab.
Washington University
St. Louis, Mo.

William L. Lurie
Information Systems Group
General Electric Company

David C. Evans
Director
Computer Science
University of Utah
Salt Lake City

Sidney Fernbach
Head, Computation Laboratory
University of California
Lawrence Radiation Laboratory
Livermore, Calif.

Jerrier A. Haddad
Vice President for Engineering,
Programming and Technology
IBM Corporation
Armonk, N.Y.

Joseph C. R. Licklider
Director
Project MAC
Cambridge, Mass.

John R. Meyer
President
National Bureau of Economic Research
New York City

Nathan M. Newmark
Head, Dept. of Civil Engineering
University of Illinois at Urbana

Kenneth Olsen
President
Digital Equipment Corporation
Maynard, Mass.

Alan J. Perlis
Head, Dept. of Computer Science
Carnegie-Mellon University
Pittsburgh, Pa.

J. Barkley Rosser
Director
Mathematics Research Center
U.S. Army
University of Wisconsin
Madison, Wis.

Alan Westin
Dept. of Public Law and Government
Columbia University
New York City

EXECUTIVE SECRETARY
Warren C. House

Financial Support

Funds for the operation of the Board are provided by both Federal Government and private sources. An initial grant of $100,000 has been made by the Advanced Research Projects Agency of the Department of Defense. It is anticipated that at least an equal amount will be contributed annually by industry, trade associations, professional societies and other organizations directly interested in computer science and engineering.

Activities

The overall assignment of the Board is to study the present and potential application of information-processing technology to various areas of government, commerce, industry and education and to assess the impact of this technology on the individual. To carry out its task, the Board set up four panels to make an initial exploration of areas of high priority.

These are the:

Education Panel—to investigate the training of computer science and engineering personnel with the aim of avoiding future shortages, and to evaluate the role of computers in the actual process of instruction.

Research & Development Panel—to explore the practical and theoretical aspects of the design of hardware, software and hardware-software systems.

National Programs Panel—to inquire into the interrelations of people and information that make up our national management systems.

Data Base Panel—to compile facts on the present and predictable future of computer research and development, manufacture and usage.

Procedure

The Board reports directly to the Council of the National Academy of Sciences, which is the governing body of the National Academy of Sciences. Through committees organized by the National Research Council, some 7,000 scientists and engineers from all parts of the country now serve as advisors to both the National Academy of Sciences and the National Academy of Engineering in their official function of providing guidance to the Federal Government on matters pertaining to science and technology. As part of this close-knit structural organization, the Computer Science and Engineering Board is able to maintain liaison with all groups in both the National Academy of Sciences and the National Academy of Engineering whose work has bearing on its own.

Headquarters of the Board are located in the National Academy of Sciences building at
2101 Constitution Avenue, N.W., Washington, D. C. 20418.

THE
NATIONAL
RESEARCH
COUNCIL

INFORMATION

FOR MEMBERS OF DIVISIONS,
COMMITTEES,
BOARDS, AND PANELS

FOREWORD

During its first half century, the commitments of the National Research Council have multiplied and become increasingly complex; the number of scientists and engineers serving on its boards, committees, and panels has likewise increased manyfold. We shall outline briefly here the scope of the Council's current activities and describe some of the most important elements of its establishment and development.

One is immediately struck by the diversity of the Council's concerns extending across the entire spectrum from undirected scientific research to immediately practical applications. Its extraordinary versatility is made possible by its unique organizational structure. In its ability to expand or contract —to adapt—through the acceptance of new tasks and the completion of old ones, it is remarkably flexible, its flexibility made possible by procedures that are as much a matter of sound tradition as of formal rules.

Stemming from its special concern for the issues in which science and the public welfare are closely interrelated, the Council is responsive to the needs and problems of both public and private agencies. But in the conduct of its affairs, it is independent of partisan external pressures and thus enjoys an objectivity that is crucial to the successful fulfillment of its role in service to science, technology, and the national interest.

The respect and prestige that the National Research Council has earned enable it to draw upon the talents and resources of the entire scientific and engineering community in the performance of its tasks. At the same time, it can and must operate selectively, undertaking only those endeavors for which its special capabilities are uniquely appropriate and which are clearly relevant to significant issues of the times.

I hope the following summary statement of the aims and operations of the National Research Council will serve not only to introduce those unfamiliar with it to the complexities, the challenges, and the special attributes of this unique institution, but also to refocus the interests of those who have known these facts for some time.

Frederick Seitz
Chairman

July 1, 1967

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
NATIONAL ACADEMY OF ENGINEERING

THE NATIONAL ACADEMY OF SCIENCES

The National Academy of Sciences is a private honorary organization of more than 750 scientists and engineers elected to lifetime membership on the basis of outstanding contributions to knowledge. Established by a congressional act of incorporation signed by Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together notably qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its congressional charter, the Academy is also called upon to act as an official —yet independent—adviser to the federal government in matters of science and technology. This provision accounts for the close ties that have always existed between the Academy and the government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the government.

THE NATIONAL ACADEMY OF ENGINEERING

The National Academy of Engineering is a private, honorary organization of about 200 engineers, elected to lifetime membership on the basis of outstanding contributions to engineering theory and practice or unusual accomplishments in pioneering new and developing fields of technology. It was established on December 5, 1964, when the Council of the National Academy of Sciences, under its act of incorporation, adopted articles of organization to bring the National Academy of Engineering into being. The National Academy of Engineering is independent and autonomous in its organization and the election of its members, and is closely coordinated with the National Academy of Sciences in its advisory activities. The two academies join in the furtherance of science and engineering and share the responsibility of advising the federal government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL

The National Research Council is an agency organized in 1916 by the National Academy of Sciences, at the request of President Wilson, to enable the broad community of United States scientists and engineers to associate their efforts with those of the more limited membership of the Academy in service to science and the nation. It now serves both the National Academy of Sciences and the National Academy of Engineering in the discharge of their responsibilities. The members of the National Research Council and the members of its committees, boards, and panels are drawn from governmental, academic, industrial, and other private organizations and institutions throughout the country.

Supported by private and public contributions, grants, and contracts, and with voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and the National Research Council work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

History of the National Research Council

In 1916, as the nation moved to face the crises of the first World War, the officers of the National Academy of Sciences and President Wilson agreed that the Academy might advantageously organize the scientific resources of educational and research institutions in the interest of national security and welfare.

As a first step, the Academy appointed an organizing committee under the chairmanship of the noted American astronomer, George Ellery Hale. Within two months, the Academy had received and approved a plan of procedure, calling for the formation of a "National Research Council, whose purpose shall be to bring into cooperation existing governmental, educational, industrial, and other research organizations with the object of encouraging the investigation of natural phenomena, the increased use of scientific methods in strengthening the national defense, and such other applications of science as will promote the national security and welfare."

In leading the work of the organizing committee, however, Hale adhered to a larger objective. As he said in a later report, "It was recognized from the outset that the activities of the committee should not be confined to the promotion of researches bearing directly on military problems, but that true preparedness would best result from the encouragement of every form of investigation, whether for military or industrial application, or for the advancement of knowledge without regard to its immediate practical bearing."

So prompt was the response from other institutions (the Engineering Foundation, for example, placed its entire income for a year at the disposal of the Council as well as the services of its secretary, Cary T. Hutchinson), that on July 26, 1916, three months after the meeting with President Wilson, four committees were already at work: on Nitric Acid and on Organic Chemicals, in cooperation with the American Chemical Society; on Preventive Medicine, with the Committee on Physicians and Surgeons; and on Communications, with the American Physical Society and the American Institute of Electrical Engineers.

By the end of the war, research groups organized by the Council had developed effective listening devices for determining the bearing of attacking submarines and aircraft, fire-control systems for antiaircraft guns, and radio-telephone communication between airplanes. The Committee on Psychology had prepared a vast program for the selection of officers and the classification of draftees through the introduction of the first intelligence test to be used by the military; and the Committee on Optical Glass had succeeded in raising the U. S. production of that valuable commodity from zero to 20,000 tons a month. Other Council activities in the military field included the development of an accurate bombsight, the first production of helium from natural gas, the investigation of the phenomena of traumatic shock, and the development of effective insecticides.

The extent and quality of the services of the National Research Council during the war led President Wilson, on May 11, 1918, to request the Academy to perpetuate the institution.

The work of the National Research Council continued beyond the armistice. Among significant developments was the creation of the National Research Council Postdoctoral Fellowships, which were clearly forerunners of the present-day pattern of fellowship awards and which, by permitting a new generation to become involved in creative research at home and abroad, contributed significantly to placing the United States among the world leaders in scientific research. It was in this period, too, that the involvement of the United States in international science affairs was underscored by the formation of an organization that was to become the International Council of Scientific Unions, to which the U. S. scientific community now adheres through at least two dozen National Research Council divisional committees. In another move, the Council recognized the oncoming revolution in transportation occasioned by the private automobile and established, in 1921, the Highway Research Board, which has played a central national advisory role for nearly 50 years. To these few examples should be added a major collaborative effort of the Division of Physical Sciences and the Division of Chemistry and Chemical Technology—the monumental *International Critical Tables of Numerical Data of Physics, Chemistry, and Technology.*

The term "Institute" is variously used in the National Research Council, but this label is applied to several bodies specifically designed to encourage voluntary participation by groups of interested industrial concerns and others in the work of an established Council board or committee. The first of these, the Industrial Research Institute, was formed in 1938. In later years the Building Research Institute, Agricultural Research Institute, and others were established.

The role of the Division of Engineering and Industrial Research in promoting research by industry was so successful that by 1939 its chairman, Vannevar Bush, was able to point out that current expenditures by industry for this purpose nearly equaled those of scientific institutions, universities, and the federal government combined.

World War II brought new dimensions of responsibility to the National Research Council. All divisions were affected, but especially the Division of Medical Sciences. In anticipation of military requirements, the division chairman had established between May 1940 and July 1941, with private funds, 41 advisory committees on military medicine and surgery. The Division played an instrumental role in the development of the new field of aviation medicine, provided for the clinical evaluation and testing of penicillin and quinine substitutes, recommended the battlefield use of sulfadiazine and sulfanilamide and the use of blood plasma as a substitute material for transfusion.

The Division of Physical Sciences played a key role in encouraging the government to proceed with the development of an atomic weapon. The Office of Scientific Personnel was organized and gave major assistance to the government in the location and recruitment of technical personnel needed to design, build, and operate the highly sophisticated weapons of modern warfare. The Division of Engineering and Industrial Research organized and operated advisory groups concerned with the supply and utilization of minerals and metals to meet war-time problems of both the military and industry, an activity that continues in the work of the Materials Advisory Board.

The cessation of hostilities at the end of World War II did not lead to a reduction in the activities of the Council. The new needs of the federal government for scientific and technological advice continued after the war and altered the character of both the National Research Council and the Academy. As the Council took on assignments of a kind that brought it close to the heart of public policy considerations, the Academy proceeded to strengthen its administrative organization. In 1950, a Governing Board was created to bring the Council of the Academy and the chairmen of the National Research Council divisions into joint session for the consideration of policy and of proposed activities. In 1953, an executive officer was added to the staff to add further strength and effectiveness to the administrative function of the executive office.

Activities and accomplishments of the National Research Council have been both expanded and diversified since the war. In 1946, President Truman requested the creation of a group of medical scientists to investigate the consequences to the human population of the dropping of atomic bombs on Hiroshima and Nagasaki. The work of that group continues under the direction of the Atomic Bomb Casualty Commission, whose laboratories in Japan are the only laboratories currently operated directly by the National Academy of Sciences or the Council. With support from the Rockefeller Foundation and at the request of the Atomic Energy Commission, the Committees on the Biological Effects of Atomic Radiation were established; summary reports issued by these committees have served as basic documents in the field.

In 1948, the American Institute of Biological Sciences was created within the Division of Biology and Agriculture, and the American Geological Institute within the Division of Earth Sciences. The AIBS became independent in 1955, as did the AGI a few years later. These and other scientific organizations have been fostered in their beginnings by the National Research Council.

The Navy, made conscious of the potentials of science for its purposes during the war, asked the Academy to create a Committee on Undersea Warfare. Through this group, important contributions were made in the development of the nuclear submarine, the Polaris program, and deep-diving vehicles. A five-year study of operations of cargo ships in the San Francisco Bay Area was completed for the government by the Maritime Cargo Transportation Conference (now the Maritime Transportation Research Board) of the National Research Council.

The Food and Nutrition Board began development in 1960 of a program of biological and clinical research on means to meet protein needs of infants and pre-school children in protein-deficient areas—a program now receiving major international emphasis. The National Academy of Sciences and the National Research Council were instrumental in the development of two of the great international scientific programs of our time—the International Geophysical Year and the International Years of the Quiet Sun. Council committees are now engaged in developing the U. S. components of the International Biological Program and the International Hydrological Decade.

Major national problems receiving impressive attention from Council divisional committees include, currently, weather modification, desalination of sea water, water resources, pollution, the sonic boom, and drug efficacy. With the exception of the last, major reports have been produced and forwarded to the relevant government agencies.

Under the general aegis of the Committee on Science and Public Policy of the National Academy of Sciences, with cooperation from the relevant divisions of the National Research Council, major reports are being prepared on the status, the outlook, and the needs of the principal scientific disciplines. Comprehensive reports have already been published in astronomy, chemistry, physics, and the plant sciences, and reports are in progress in mathematics, the life sciences, and the behavioral and social sciences. These reports constitute the principal statements from their respective disciplines on the state of science and its potentials for progress and productivity in the years immediately ahead.

Since 1950, the combined budget of the National Research Council and the National Academy of Sciences—joined by the National Academy of Engineering in 1964—has increased from $6 million to more than $20 million. The full-time combined staff has grown from 350 to 660. As the well-being of the nation comes increasingly to depend on its scientific and technological strength and development, the work of the National Research Council will continue to grow in size and in its significance to human welfare.

General Functions and Responsibilities of the National Research Council

The general functions and responsibilities of the National Research Council are evolving in response to the needs of society. Thus, during its history the Council has focused special attention on problems relating to stimulation of research, to national defense, to industrial progress, to international cooperation, to communication in science and technology. The following list of major functions and responsibilities will embrace most of its current activities:

1 To stimulate research in science and engineering, including the agricultural, medical, behavioral, and social sciences.

2 To provide advice and assistance, on request, to agencies of the federal government and to private organizations on matters of science and technology.

3 To identify scientific and engineering problems important to the national welfare and to aid in their solution; these include, but are not limited to, issues relating to national defense, public health and welfare, industrial research and development, the conservation and use of natural resources, and the quality of our environment.

4 To examine problems relating to the collection, collation, and dissemination of scientific and technical information and to aid in their solution.

5 To support and conduct studies and analyses on manpower for science, engineering, and other professions, including training, education, supply, requirements, and utilization.

6 To support and conduct programs providing opportunities for fellowships, research associateships, and similar programs for training and research in the fields of interest in the National Research Council.

7 To examine current and future needs for research support in the various scientific and engineering disciplines.

8 To promote cooperation in research at home and abroad, including the application of science and engineering to the needs of developing countries.

9 To promote international cooperation in science and engineering and to serve as a medium through which the scientific and engineering communities may speak effectively to their foreign counterparts on matters of research, education, and information exchange.

10 To examine urgent social problems involving science and technology.

11 To provide a forum for the development and exchange of new and possibly controversial ideas in science, engineering, and technology and their application to the social welfare.

A primary objective of the National Research Council is to bring together scientists and engineers of exceptional competence to deal with scientific and engineering problems and to exchange information in furtherance of research. Because of the breadth of its interests, the Council enjoys a unique opportunity to organize broad attacks on problems of national importance that may benefit from the attention of investigators in diverse fields of science and technology. The tasks vary widely in nature and in the duration and type of effort required; patterns of organization must be flexible so that particular problems can be approached in the most effective manner.

The scientists and engineers who carry out much of the work of the National Research Council are appointed to committees administered by one of the Divisions or Offices of the Council: Behavioral Sciences, Biology and Agriculture, Chemistry and Chemical Technology, Earth Sciences, Engineering, Mathematical Sciences, Medical Sciences, Physical Sciences, Office of Scientific Personnel, Office of the Foreign Secretary. The work of each division is under the direction of a chairman, appointed by the Council of the National Academy of Sciences (in the Division of Engineering, upon nomination by the Council of the National Academy of Engineering). The Office of the Foreign Secretary serves the two academies and the National Research Council, providing a focal point for all institutional relationships in international scientific and technical affairs.

The National Research Council currently has about 400 committees, boards, and panels whose members are drawn principally from the academic community, government, and industry. Although the lines of definition and distinction cannot always be sharply drawn, each of these types of grouping is engaged in activities for which it is especially well adapted. Committees may be *ad hoc* or standing, depending upon the character of their tasks. Boards are generally organized to deal with large, interdisciplinary problems of relatively long duration—such as materials, food and nutrition, highway research. Panels typically tend to be *ad hoc*, and often subordinate to larger groups—committees or boards. Special offices and centers have been organized to provide continuing services to science and the government. Typical of these are the Office of Scientific Personnel, the Office of Critical Tables, and the Advisory Center on Toxicology.

All appointments of members of committees, boards, and panels are made by or on behalf of the president of the National Academy of Sciences, the president of the National Academy of Engineering, or both, as appropriate. Appointments are generally made on the basis of nominations submitted by a division or office after preliminary analysis of the task to be performed.

The advisory groups of the Council are generally self-limiting, both in duration and in extent of activity. In order to maintain maximum flexibility in dealing with problems identified by its own members or brought to its consideration by others, the Council seeks to avoid long-term or open-ended operational responsibilities. Since it is not an agency of the government, the Council recommends rather than establishes programs, budgets, and standards.

Actual expenses incurred in providing advice and other services are reimbursed by the requesting

agency, public or private, but in no case does the National Academy of Sciences receive compensation for such services. The injunction against compensation applies to all who serve under the charter of the National Academy of Sciences, and thus to the members of the National Research Council and the members of its boards, committees, and panels as well as the members of both the National Academy of Sciences and the National Academy of Engineering. Such individuals are, of course, reimbursed for transportation, subsistence, and out-of-pocket expenses incurred when undertaking assignments for the Council or either of the two academies.

Guidelines for Division Officers, Council Members, Members of Committees, and Staff Members

Certain precepts and procedures have been formulated for the information and guidance of division officers, Council members, members of committees (boards, panels, and working groups), and staff members. These are outlined in some detail in a separate publication but are noted here in an abbreviated form.

1 *Formulation of policy.* Policy questions may be brought to the attention of the presidents of the two academies at any time. There is opportunity for broad discussion of such questions at the regular meetings of the Governing Board of the National Research Council, which consists of members of the Council of the National Academy of Sciences, members of the Executive Committee of the National Academy of Engineering, chairmen of the divisions of the National Research Council, and the chairman of the advisory committee for the Office of Scientific Personnel. The president of the National Academy of Sciences serves also as chairman of the National Research Council.

2 *Privileged nature of committee deliberations.* Positions taken by any individual participating in committee discussions are to be regarded as fully privileged. The minutes, working papers, vote tallies, transcripts, and other records of the deliberations of a committee are to be considered privileged documents not releasable outside the National Research Council except by agreement of the responsible officers and with the consent of the committee.

3 *Reports, resolutions, publications.* Reports of an advisory committee to any government agency or official in response to a duly accepted request, or in compliance with an agreement for advisory services, are to be considered the property of that agency or official insofar as disclosure and distribution are concerned, unless a specific agreement to the contrary has been made. Such reports should not be transmitted to other agencies or officials without the approval of the agency or official concerned.

Recommendations and judgments that deal with agency policy or with matters of broad national policy should be reviewed by the executive office of the National Research Council before they are formally transmitted or otherwise promulgated outside the Council in reports, resolutions, or publications.

4 *Public release of information.* Information released by any member of a committee or its staff with regard to matters before the committee is likely to be construed as expressing the views of the entire group. Where a statement is necessary, committees should agree on a spokesman, usually the chairman, who will make any public statement or carry on any appropriate external discussion of the work of the committee.

The Office of Information is available for consultation and assistance concerning public release of information relating to the work of a committee board or panel. In every case the Office of Information should be given an opportunity to review plans for the public release of information.

5 *Relationships with White House and Congress. Formal* communications with the White House and members of Congress, committees of Congress, or their staffs, with respect to any activity of the National Research Council should be carried on through the president of the National Academy of Sciences unless alternative arrangements have been authorized by him.

Should it become necessary for any member of a committee or of the staff to engage in informal discussions of committee matters with the White House or with members of Congress, committees of Congress, or their staffs, he should keep his committee chairman and the responsible division chairman informed.

6 *Conflicts of interest.* Individuals who accept Council membership, committee membership, or service as officers or staff members are responsible for considering the possibility of bias that may derive from such factors as their institutional affiliation, consulting agreements, grant responsibilities, and previous employment. Both actual and apparent conflicts of interest must be avoided wherever possible. Where conflicts cannot be avoided because of the nature of the problem, they must be recognized and stated explicitly.

The Role of Members in National Research Council Activities

The activities of the National Research Council cover a wide spectrum; they range from evaluating the biological effects of ionizing radiation to stimulating and correlating research on all aspects of the building industry, from advising the Navy Department on long-range scientific and technical problems in undersea warfare to reviewing and evaluating fellowship applications in all fields of science and engineering. The 400 active boards, committees, and panels of the Council now involve a membership of about 5,000 scientists and engineers. Essential to the proper functioning of these advisory groups is the full-time staff of 660 employees. It is in the context of these activities that the role of the 300 members of the National Research Council must be defined.

Nominations for membership in the National Research Council are made by the affiliated scientific and engineering societies, by the heads of departments or agencies of the federal government, or by the chairman of one of the divisions of the Council. Appointments are made by the president of the National Academy of Sciences in his capacity as chairman of the National Research Council. Appointments are for an initial term of three years and may be renewed, although periodic rotation in membership is considered to be generally desirable. Members of the National Research Council serve in one of the eight divisions of the Council. The specific functions that members may perform will depend in part upon the policies and programs of their respective divisions, upon their willingness to devote time and energy to these programs, and upon the backgrounds and skills they bring to their divisions.

The role of members is primarily advisory. Illustrative of the functions that a member may be called upon to perform, usually at the discretion and upon the request of his division chairman, are the following:

1 Serving as an important channel of communication between his scientific or engineering society and the Council. This will be facilitated if the member is intimately acquainted with his society's current interests and activities and the manner in which it operates.

2 Advising his division concerning problems as well as needs and opportunities in his scientific or engineering discipline. Distinction in his special field of interest, and awareness of its interrelationships with others, will be important assets in identifying policy issues.

3 Advising his division on its programs and policies. Members' interests should include not only research or teaching in the narrower sense of these words, but also science and engineering activities within the broad context of our national culture.

4 Serving on boards, committees, or panels of one of the divisions when his talents and experience are appropriate to the particular task at hand.

5 Assisting in the critical review of reports during their preparation by boards, committees, and panels of his division.

6 Rendering advice concerning nominations of potential members of National Research Council boards, committees, and panels.

7 Participating in the symposia and program reviews of his division at the annual meetings of the Council.

Although members of the National Research Council are nominated by scientific and technical societies, by government agencies, or as members at large, they are not to be considered as instructed delegates of their societies or agencies; rather, they are expected to contribute to the work of their respective divisions in such ways as their individual scientific, technical, or other competencies may suggest.

In addition to the members of the National Research Council as defined above, liaison representatives may be nominated by government agencies on the basis of mutual interests of the National Research Council division and the agency or organization concerned. Appointments of liaison representatives are made by or on behalf of the president of the National Academy of Sciences.

SOCIETIES AFFILIATED WITH THE NATIONAL RESEARCH COUNCIL, JULY 1, 1967

Division of Behavioral Sciences

American Anthropological Association
American Economic Association
American Historical Association
American Political Science Association
American Psychological Association
American Sociological Association
Association of American Geographers
Linguistic Society of America

Division of Biology and Agriculture

American Association for Laboratory Animal Science
American Association of Anatomists
American Dairy Science Association
American Farm Economic Association
American Fisheries Society
American Genetic Association
American Institute of Nutrition
American Physiological Society
American Phytopathological Society
American Society for Cell Biology
American Society for Experimental Pathology
American Society for Horticultural Science
American Society for Microbiology
American Society for Pharmacology and Experimental Therapeutics
American Society of Agricultural Engineers
American Society of Agronomy
American Society of Animal Science
American Society of Biological Chemists
American Society of Ichthyologists and Herpetologists
American Society of Limnology and Oceanography
American Society of Mammalogists
American Society of Parasitologists
American Society of Plant Physiologists
American Society of Plant Taxonomists
American Society of Range Management
American Society of Zoologists
American Veterinary Medical Association
Biometric Society: Eastern and Western North American Regions
Biophysical Society
Botanical Society of America
Crop Science Society of America
Ecological Society of America
Entomological Society of America
Genetics Society of America
Institute of Food Technologists
Mycological Society of America
Paleontological Society
Phycological Society of America
Poultry Science Association

Radiation Research Society
Society for Developmental Biology
Society of American Foresters
Society of General Physiologists
Society of Nematologists
Society of Protozoologists
Society of Systematic Zoology
Soil Science Society of America
Weed Society of America
Wildlife Society

Division of Chemistry and Chemical Technology

American Association of Clinical Chemists
American Ceramic Society
American Chemical Society
American Crystallographic Association
American Institute of Chemical Engineers
American Nuclear Society
American Oil Chemists' Society
American Society for Pharmacology and Experimental Therapeutics
American Society of Biological Chemists
Electrochemical Society
Geochemical Society

Division of Earth Sciences

American Association of Petroleum Geologists
American Congress on Surveying and Mapping
American Geographical Society
American Geophysical Union
American Institute of Mining, Metallurgical, and Petroleum Engineers
American Meteorological Society
American Society of Limnology and Oceanography
American Society of Photogrammetry
Association of American Geographers
Clay Minerals Society
Geochemical Society
Geological Society of America
Mineralogical Society of America
Paleontological Society
Seismological Society of America
Society of Economic Geologists
Society of Economic Paleontologists and Mineralogists
Society of Exploration Geophysicists
Society of Vertebrate Paleontology
Soil Science Society of America

Division of Engineering

American Institute of Aeronautics and Astronautics
American Institute of Architects
American Institute of Chemical Engineers
American Institute of Industrial Engineers
American Institute of Mining, Metallurgical, and Petroleum Engineers
American Iron and Steel Institute
American Nuclear Society
American Society for Engineering Education
American Society for Metals
American Society for Testing and Materials
American Society of Agricultural Engineers
American Society of Civil Engineers
American Society of Heating, Refrigerating, and Airconditioning Engineers
American Society of Mechanical Engineers
American Welding Society

Building Research Institute
Engineering Foundation
Illuminating Engineering Society
Industrial Research Institute
Institute of Electronics Engineers
Institute of Traffic Engineers
Instrument Society of America
Society of Automotive Engineers
Society of Naval Architects and Marine Engineers
Society of Photographic Scientists and Engineers

Division of Mathematical Sciences

American Mathematical Society
American Physical Society
Association for Computing Machinery
Association for Symbolic Logic
Biometric Society: Eastern and Western North American Regions
Econometric Society
Institute of Management Sciences
Institute of Mathematical Statistics
Mathematical Association of America
Operations Research Society of America
Society for Industrial and Applied Mathematics

Division of Medical Sciences

American Academy of Neurology
American Academy of Orthopaedic Surgeons
American Academy of Pediatrics
American Association for Cancer Research
American Association of Anatomists
American Association of Immunologists
American Association of Pathologists and Bacteriologists
American College of Obstetricians and Gynecologists
American College of Physicians
American College of Surgeons
American Dental Association
American Federation for Clinical Research
Amedican Medical Association
American Neurological Association
American Physiological Society
American Psychiatric Association
American Public Health Association
American Roentgen Ray Society
American Society for Clinical Investigation
American Society for Experimental Pathology
American Society for Microbiology
American Society for Pharmacology and Experimental Therapeutics
American Society of Biological Chemists
American Society of Tropical Medicine and Hygiene
American Surgical Association
American Veterinary Medical Association
Association of American Physicians
Society for Investigative Dermatology
Society for Pediatric Research

Division of Physical Sciences

Acoustical Society of America
American Astronomical Society
American Crystallographic Association
American Geophysical Union
American Institute of Physics
American Meteorological Society
American Physical Society
Biophysical Society
Optical Society of America
Radiation Research Society

MEMBERS OF THE GOVERNING BOARD, NATIONAL RESEARCH COUNCIL, JULY 1, 1967

Members of the Council, National Academy of Sciences

Frederick Seitz, President
G. B. Kistiakowsky, Vice President
Merle A. Tuve, Home Secretary
Harrison Brown, Foreign Secretary
E. R. Piore, Treasurer
H. W. Bode
Herbert E. Carter
Fred Eggan
Katherine Esau
Wallace O. Fenn
Paul J. Flory
Jesse L. Greenstein
Sterling B. Hendricks
Colin M. MacLeod
E. J. McShane
William W. Rubey
Alvin M. Weinberg

Members of the Executive Committee, National Academy of Engineering

Eric A. Walker, President
Clarence H. Linder, Vice President
Thomas C. Kavanagh, Treasurer
George E. Holbrook
Nathan M. Newmark
John R. Pierce
Frederick Seitz

Chairmen of National Research Council Divisions

R. H. Bing, Mathematical Sciences
John R. Borchert, Earth Sciences
R. Keith Cannan, Medical Sciences
Kingsley Davis, Behavioral Sciences
Paul J. Flory, Chemistry and Chemical Technology
E. L. Goldwasser, Physical Sciences
John A. Hutcheson, Engineering
A. G. Norman, Biology and Agriculture

Chairman, Advisory Committee, Office of Scientific Personnel

Bryce Crawford, Jr.

STAFF OFFICERS, JULY 1, 1967

Executive Officer *John S. Coleman*

Business Manager *G. D. Meid*

Executive Secretaries, Divisions and Offices

Joseph W. Berg, Earth Sciences
Leon W. Cohen, Mathematical Sciences
Henry David, Behavioral Sciences
Henry T. Gannon, Medical Sciences
John C. Kohl, Engineering
Hugh Odishaw, Physical Sciences
Martin A. Paul, Chemistry and Chemical Technology
Russell B. Stevens, Biology and Agriculture
W. Murray Todd, Office of the Foreign Secretary

Directors of Offices

William C. Kelly, Office of Scientific Personnel
Howard J. Lewis, Office of Information

Secretary, National Academy of Engineering

Harold K. Work

JULY 1, 1967

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

GUIDELINES

FOR DIVISIONAL OFFICERS
MEMBERS OF COMMITTEES
AND STAFF

FOUNDED 1863

WASHINGTON, D.C. 1964

THE COUNCIL OF THE NATIONAL ACADEMY OF Sciences has formulated certain precepts and procedures for the information and guidance of the divisional officers, members of committees, and staff acting under the authority of the Academy and the National Research Council. In what follows, the term *committee* is intended to include the wide range of committees, boards, panels, working groups, and similar bodies that are appointed in the course of our activities.

There are several reasons for the Council's action:

1. The number of scientific and technical groups within the NAS-NRC is now so large, and the responsibilities that have been accepted under the Act of Incorporation of the Academy are so broad, that it has become necessary to formalize certain channels and procedures.

2. Because reports or statements associated with any part of the NAS-NRC are likely to be taken to represent the official views of the institution as a whole, procedures for the transmittal or release of such reports and statements must be established and understood.

3. As science comes more and more into the public eye, pervading many questions of national policy, the timely issuance to the public of reports and other pertinent information relating to our activities must engage our careful attention.

4. The growing involvement of leading scientists and engineers in undertakings receiving public support means that care must be taken to avoid conflicts of interest that are such as to derogate from the effort to provide objective advice to public agencies in response to multiplying needs and requests.

The following paragraphs, then, contain information and guidelines to assist those who serve science and the nation through the undertakings of the NAS-NRC.

FORMULATION OF POLICY

The formulation of policy for the Academy and Research Council is the responsibility of the President and elected Council of the Academy. Policy is determined by the President and Council after consultation as appropriate with the chairmen and members of divisions, with members of committees, and with members of the staff. Policy questions may be brought to the President's attention at any time, and there is opportunity for broad discussion of such questions at the regular meetings of the Council of the Academy and the Governing Board of the Research Council. The President, division chairmen, and staff undertake to keep the members of the Research Council and of committees informed of policy matters affecting their responsibilities.

PRIVILEGED NATURE OF COMMITTEE DELIBERATIONS

The effectiveness of the Academy and Research Council in dealing with scientific issues and with issues in the relationship of science to the national interest requires an atmosphere for deliberations that encourages full and free discussion of all relevant matters. To safeguard this atmosphere the principle must be observed that the positions taken by any individual participating in committee discussions are to be regarded as fully privileged. Such positions must not, except by his own desire, be identified with the individual outside the deliberations of the committee.

The minutes, working papers, vote tallies, transcripts, and other records of the deliberations of a committee are to be considered privileged documents not releasable outside the NAS-NRC except by agreement of the responsible officers of the NAS-NRC and with the consent of the committee.

REPORTS, RESOLUTIONS, PUBLICATIONS

Reports of an advisory committee to any governmental agency or official in response to a duly accepted request, or in compliance with an agreement for advisory services, are to be considered the property of that agency or official insofar as disclosure and distribution are concerned, unless a specific agreement to the contrary has been made. Such reports should not without the approval of the agency or official concerned be transmitted to other agencies or officials, lest the confidential relationship between the Academy and those it advises be jeopardized.

Recommendations and judgments that deal with agency policy or with matters of broad national policy are likely to be construed as representing the official views of the NAS-NRC as an institution. They should be reviewed by the office of the President of the Academy before they are formally transmitted or otherwise promulgated outside the NAS-NRC in reports, resolutions, or publications. Recommendations and judgments concerned exclusively with scientific or technical content of agency programs are not construed to be policy matters.

PUBLIC RELEASE OF INFORMATION

The Office of Information of the NAS-NRC is available for consultation on the desirability of public release of information on topics arising from the work of committees. That office can assist in the preparation of such releases, and in all cases should be given an opportunity to review plans for the public release of information.

Verbal statements to the press by any member of a committee or its staff with regard to matters before the committee are likely to be construed as expressing the views of the entire group. Where a statement is necessary, committees should agree on a spokesman, usually the chairman, who will make any public statement or carry on any press discussion of the work of the committee. The spokesman should, whenever possible, consult with the Office of Information, using the regular staff channels serving his committee, and should seek guidance from the appropriate division office or the office of the President of the Academy if the issue is in a controversial area of public or national policy.

WHITE HOUSE AND CONGRESSIONAL RELATIONSHIPS

Formal communications with the White House and Members of Congress, committees of Congress, or their staffs, with respect to any activity of the NAS-NRC should be carried on through the President of the Academy unless alternative arrangements have been authorized by him.

Should it become necessary for any member of a committee or of the staff to involve himself in informal discussions of committee matters with the White House or with Members of Congress, committees of Congress, or their staffs, he should keep his chairman and the responsible division chairman informed. In general, it is preferable that the committee chairman act for the committee in such situations, after consultation with the appropriate division chairman or the President of the Academy.

Should a divisional officer or committee or staff member be invited to testify before a committee of Congress on matters relating to any activity of the NAS-NRC, he should inform the President of the Academy so that any internal policy or procedural questions can be resolved.

CONFLICTS OF INTEREST

It is necessary for the NAS-NRC to be increasingly alert to conflict-of-interest situations that may arise within its structure. These can appear whether or not the possibility of personal profit is inherently present. To insure their competence, committees are likely to include in their membership many whose livelihood is derived wholly or in part from activities in the very fields in which the committees render advice. Individuals who accept committee membership, or service as officers or staff members, are responsible for considering the possibility of bias that may derive from such factors as their institutional affiliation, consulting agreements, grant responsibilities, and previous employment. If confidence is to be maintained in the objectivity of NAS-NRC judgments and advice, both actual and apparent conflicts of interest must be avoided wherever possible. Where conflicts cannot be avoided because of the nature of the problem, they must be recognized and explicitly stated. With the chairmen of committees and with the staff must rest a special responsibility for being perceptive about such situations and for anticipating them wherever possible. Doubtful cases should be reviewed with the President of the Academy.

DIVISION AND STAFF RESPONSIBILITIES

Nothing in this statement is intended to alter established lines of communication within the NAS-NRC. Committees organized under divisions of the National Research Council should use the channels and facilities of the division to resolve problems that arise. Division chairmen are directly responsible to the President of the Academy, who is Chairman of the National Research Council, for the general oversight of the scientific programs of their divisions and for such recommendations as they feel to be desirable in matters of policy and administration.

It is the responsibility of staff officers, insofar as they can, to assist the President of the Academy and the chairmen of divisions in the administration of the provisions contained herein, to assist committees in observing them, and to invite attention to the need for additions or revisions.

FREDERICK SEITZ, *President*

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

GUIDELINES

FOR DIVISIONAL OFFICERS
MEMBERS OF COMMITTEES
AND STAFF

FOUNDED 1863

WASHINGTON, D.C. 1964

THE COUNCIL OF THE NATIONAL ACADEMY OF Sciences has formulated certain precepts and procedures for the information and guidance of the divisional officers, members of committees, and staff acting under the authority of the Academy and the National Research Council. In what follows, the term *committee* is intended to include the wide range of committees, boards, panels, working groups, and similar bodies that are appointed in the course of our activities.

There are several reasons for the Council's action:

1. The number of scientific and technical groups within the NAS-NRC is now so large, and the responsibilities that have been accepted under the Act of Incorporation of the Academy are so broad, that it has become necessary to formalize certain channels and procedures.

2. Because reports or statements associated with any part of the NAS-NRC are likely to be taken to represent the official views of the institution as a whole, procedures for the transmittal or release of such reports and statements must be established and understood.

3. As science comes more and more into the public eye, pervading many questions of national policy, the timely issuance to the public of reports and other pertinent information relating to our activities must engage our careful attention.

4. The growing involvement of leading scientists and engineers in undertakings receiving public support means that care must be taken to avoid conflicts of interest that are such as to derogate from the effort to provide objective advice to public agencies in response to multiplying needs and requests.

The following paragraphs, then, contain information and guidelines to assist those who serve science and the nation through the undertakings of the NAS-NRC.

FORMULATION OF POLICY

The formulation of policy for the Academy and Research Council is the responsibility of the President and elected Council of the Academy. Policy is determined by the President and Council after consultation as appropriate with the chairmen and members of divisions, with members of committees, and with members of the staff. Policy questions may be brought to the President's attention at any time, and there is opportunity for broad discussion of such questions at the regular meetings of the Council of the Academy and the Governing Board of the Research Council. The President, division chairmen, and staff undertake to keep the members of the Research Council and of committees informed of policy matters affecting their responsibilities.

PRIVILEGED NATURE OF COMMITTEE DELIBERATIONS

The effectiveness of the Academy and Research Council in dealing with scientific issues and with issues in the relationship of science to the national interest requires an atmosphere for deliberations that encourages full and free discussion of all relevant matters. To safeguard this atmosphere the principle must be observed that the positions taken by any individual participating in committee discussions are to be regarded as fully privileged. Such positions must not, except by his own desire, be identified with the individual outside the deliberations of the committee.

The minutes, working papers, vote tallies, transcripts, and other records of the deliberations of a committee are to be considered privileged documents not releasable outside the NAS-NRC except by agreement of the responsible officers of the NAS-NRC and with the consent of the committee.

REPORTS, RESOLUTIONS, PUBLICATIONS

Reports of an advisory committee to any governmental agency or official in response to a duly accepted request, or in compliance with an agreement for advisory services, are to be considered the property of that agency or official insofar as disclosure and distribution are concerned, unless a specific agreement to the contrary has been made. Such reports should not without the approval of the agency or official concerned be transmitted to other agencies or officials, lest the confidential relationship between the Academy and those it advises be jeopardized.

Recommendations and judgments that deal with agency policy or with matters of broad national policy are likely to be construed as representing the official views of the NAS-NRC as an institution. They should be reviewed by the office of the President of the Academy before they are formally transmitted or otherwise promulgated outside the NAS-NRC in reports, resolutions, or publications. Recommendations and judgments concerned exclusively with scientific or technical content of agency programs are not construed to be policy matters.

PUBLIC RELEASE OF INFORMATION

The Office of Information of the NAS-NRC is available for consultation on the desirability of public release of information on topics arising from the work of committees. That office can assist in the preparation of such releases, and in all cases should be given an opportunity to review plans for the public release of information.

Verbal statements to the press by any member of a committee or its staff with regard to matters before the committee are likely to be construed as expressing the views of the entire group. Where a statement is necessary, committees should agree on a spokesman, usually the chairman, who will make any public statement or carry on any press discussion of the work of the committee. The spokesman should, whenever possible, consult with the Office of Information, using the regular staff channels serving his committee, and should seek guidance from the appropriate division office or the office of the President of the Academy if the issue is in a controversial area of public or national policy.

WHITE HOUSE AND CONGRESSIONAL RELATIONSHIPS

Formal communications with the White House and Members of Congress, committees of Congress, or their staffs, with respect to any activity of the NAS-NRC should be carried on through the President of the Academy unless alternative arrangements have been authorized by him.

Should it become necessary for any member of a committee or of the staff to involve himself in informal discussions of committee matters with the White House or with Members of Congress, committees of Congress, or their staffs, he should keep his chairman and the responsible division chairman informed. In general, it is preferable that the committee chairman act for the committee in such situations, after consultation with the appropriate division chairman or the President of the Academy.

Should a divisional officer or committee or staff member be invited to testify before a committee of Congress on matters relating to any activity of the NAS-NRC, he should inform the President of the Academy so that any internal policy or procedural questions can be resolved.

CONFLICTS OF INTEREST

It is necessary for the NAS-NRC to be increasingly alert to conflict-of-interest situations that may arise within its structure. These can appear whether or not the possibility of personal profit is inherently present. To insure their competence, committees are likely to include in their membership many whose livelihood is derived wholly or in part from activities in the very fields in which the committees render advice. Individuals who accept committee membership, or service as officers or staff members, are responsible for considering the possibility of bias that may derive from such factors as their institutional affiliation, consulting agreements, grant responsibilities, and previous employment. If confidence is to be maintained in the objectivity of NAS-NRC judgments and advice, both actual and apparent conflicts of interest must be avoided wherever possible. Where conflicts cannot be avoided because of the nature of the problem, they must be recognized and explicitly stated. With the chairmen of committees and with the staff must rest a special responsibility for being perceptive about such situations and for anticipating them wherever possible. Doubtful cases should be reviewed with the President of the Academy.

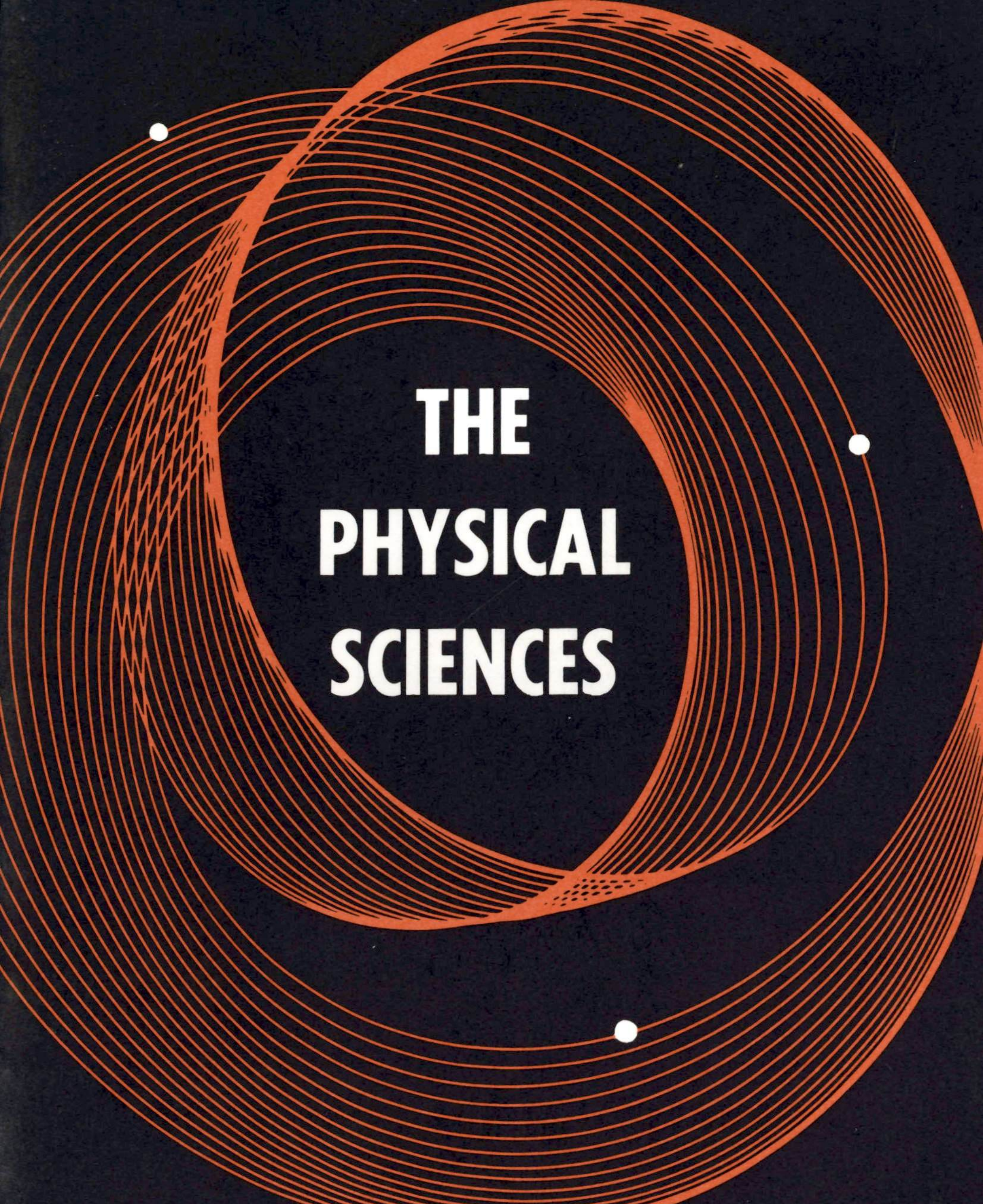
DIVISION AND STAFF RESPONSIBILITIES

Nothing in this statement is intended to alter established lines of communication within the NAS-NRC. Committees organized under divisions of the National Research Council should use the channels and facilities of the division to resolve problems that arise. Division chairmen are directly responsible to the President of the Academy, who is Chairman of the National Research Council, for the general oversight of the scientific programs of their divisions and for such recommendations as they feel to be desirable in matters of policy and administration.

It is the responsibility of staff officers, insofar as they can, to assist the President of the Academy and the chairmen of divisions in the administration of the provisions contained herein, to assist committees in observing them, and to invite attention to the need for additions or revisions.

Frederick Seitz, *President*

THE PHYSICAL SCIENCES



NATIONAL SCIENCE BOARD

1970

The cover design is a "cosmograph": the product of an invention by Edward Lias. Cosmographs are visual records of patterns produced by interfering sound waves. This modern art form has limitless variations, because each combination of frequencies produces a different diffraction pattern.

THE PHYSICAL SCIENCES

REPORT OF THE NATIONAL SCIENCE BOARD
SUBMITTED TO THE CONGRESS
1970

NATIONAL SCIENCE BOARD
NATIONAL SCIENCE FOUNDATION

Library of Congress Catalog Card No. 77-605085

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents

LETTER OF TRANSMITTAL

January 2, 1970

My Dear Mr. President:

It is my privilege to transmit herewith the second Report of the National Science Board, prepared in accordance with the provisions of Section 4(g) of the National Science Foundation Act as amended by Public Law 90-407. This Report is addressed to the present state of the physical sciences, their recent accomplishments, their apparent opportunities and challenges, and the requirements if these opportunities and challenges are to be accepted.

The physical sciences are the pacemakers of our civilization. With the materials and understanding they provide we are enabled to secure the national defense and construct a world in which our fellowmen are healthier, more comfortable, and more richly endowed, in which mankind is freed to pursue truly human endeavors. Research in the physical sciences today will, tomorrow, underlie more penetrating understanding of the nature of life in health and disease as well as find application in the countless aspects of engineering which translate scientific understanding into societal benefit.

As this Report recounts, our Nation has ample reason to be proud of its accomplishments in all areas of the physical sciences for the last two decades. Yet there is every reason to believe that the best and most rewarding science lies ahead. As in the past, each next step is more difficult, more complex, and more expensive than the last while the potential for application is seldom evident in prospect.

We recognize that the frontiers of astronomy, physics, and chemistry must appear remote from the immediacy of the problems posed by the environment and decaying cities or the complexities of foreign affairs. Yet we urge that our Nation not surrender its leading position in the worldwide scientific endeavor, that we continue in the search for that fundamental understanding which must constitute the principal legacy we may leave to succeeding generations as, in their turn, they seek to utilize the fruits of science to alleviate the condition of man. Although the precise manner of societal utilization of future scientific discoveries is unpredictable, there can be no doubt that to conduct scientific research is to construct a bridge to a brighter future.

But the magnitude of that effort must rest upon a balanced judgment of the opportunities and needs of the research endeavor on the one hand and the urgency of diverse alternative demands upon available national resources. At the same time, we are not unmindful of the danger to the national future if, in our anxiety to utilize science and scientists to combat the societal problems of the moment, we so reduce the pace and scope of the scientific endeavor itself as to fail to build a platform for tomorrow's applied science.

There are many important calls upon the public purse, and the support of science is one such. Decisions with respect to how the resources of the Federal Government are to be allocated are not a function of this Board but rather of the President and the Congress. Advocates of specific utilization of those resources must necessarily make the best possible case for those programs which they advocate. Only with such a background can the final adjudication occur.

It is precisely because other national needs are so compelling that the Board has here attempted to make the best and strongest possible case for the support of the physical sciences for consideration by those who must make the ultimate decisions.

It is to assist in formulation of these judgments, and in the hope that the seemingly urgent will not be permitted to obscure that which, in the long run, is the truly important, that this Report was prepared and is conveyed to you for transmittal to the Congress.

Respectfully yours,

Philip Handler

Philip Handler
Chairman, National Science Board

The Honorable
The President of the United States

CONTENTS

ACKNOWLEDGMENTS

The National Science Board is grateful to five consultants who joined with the Board Committee charged with the preparation of this report in the discussion and writing sessions which resulted in this document. These consultants are: Dr. Leo Goldberg, Dr. George S. Hammond, Dr. Nelson, J. Leonard, Mr. Victor McElheny, and Dr. Leonard I. Schiff.

The Board is especially indebted to Dr. Raymond J. Seeger (Senior Staff Associate, Office of the Assistant Director for Research), who served as Executive Secretary to the Committee; Dr. William E. Wright (Division Director, Mathematical and Physical Sciences), Staff Liaison to the Committee, and Dr. M. Kent Wilson (Head, Chemistry Section) for the final editing of the report.

The Board also received assistance from many individuals in the Federal Government, educational institutions, private industry, and professional societies.

The following Government agencies provided representatives to participate in a meeting concerned with the preparation of the report and to review a draft of it: Atomic Energy Commission, Department of Agriculture, Department of Commerce, Department of Defense, Department of Health, Education and Welfare, Department of the Interior, National Aeronautics and Space Administration.

The individuals noted below provided the Board with a wealth of ideas and information through written material, meetings, or comments on the penultimate version of the report: Dr. W. O. Baker (former Member, National Science Board), Vice President—Research, Bell Telephone Laboratories, Inc.; Dr. Karl H. Beyer, Jr., Senior Vice President, Research Laboratories, Merck, Sharp and Dohme; Dr. Arthur M. Bueche, Vice President, Research and Development, General Electric Company; Dr. Theodore L. Cairns, Assistant Director, Central Research Department, E. I. duPont de Nemours and Company; Dr. Paul F. Chenea, Vice President, Research Laboratories, General Motors Corporation; Dr. A. M. Clogston, Director, Physical Research Laboratory, Bell Telephone Laboratories, Inc.; Dr. Richard Crane (Chairman, Physics and Society Committee, American Institute of Physics), Professor of Physics, University of Michigan; Dr. Milan D. Fiske, Manager, Physical Sciences Branch, Research and Development Center, General Electric Company; Dr. Wayland C. Griffith (Vice Chairman, NSF Advisory Commitee for Planning) Vice President for Research and Technology, Missiles and Space Company, Lockheed Aircraft Corporation; Dr. W. E. Hanford, Vice President, Research and Development, Olin Mathiesen Chemical Corporation; Dr. Milton Harris, Chairman, Board of Directors, American Chemical Society; Dr. E. D. Kane, President, Chevron Research Company; Dr. Irving Kaplansky (Member, NSF Advisory Committee for Mathematical and Physical Sciences) Professor and Chairman, Department of Mathematics, University of Chicago; Dr. J. Ross MacDonald, Vice President, Corporate Research and Engineering, Texas Instruments, Inc.; Dr. Oscar T. Marzke, Vice President, Fundamental Research, U.S. Steel Corporation; Dr. Wendell C. Peacock, Research Scientist, Beckman Instruments, Inc.; Dr. Roland W. Schmitt, Research and Development Manager, Physical Sciences and Engineering Research and Development Center, General Electric Company; Dr. Verner Schomaker (Chairman, NSF Advisory Committee for Mathematical and Physical Sciences), Professor and Chairman, Department of Chemistry, University of Washington; Dr. Frederick T. Wall, Executive Director, American Chemical Society; Dr. Albert E. Whitford Professor of Astronomy, University of California at Santa Cruz, and Former Director, Lick Observatory, (President, American Astronomical Society).

The Advisory Committee for Mathematical and Physical Sciences of the National Science Foundation also discussed the report at two of its meetings.

Finally, the Board is indebted to Mrs. Lois S. Niemann, Administrative Assistant to the Vice President for Instruction and Research at Louisiana State University, and to the many persons at the National Science Foundation who offered advice and counsel and especially to Miss Helen Potter and the National Science Board Office for other editorial and secretarial assistance.

SUMMARY AND RECOMMENDATIONS

Preamble

The underlying premise of national science policy for two decades has been that continued strength in science and technology is essential to the welfare of the Nation and its influence and leadership in the world. We believe that policy to be still valid. No one can guarantee how rapidly scientific knowledge may become applicable to the problems which beset our world. Scientific knowledge alone is not sufficient to ensure that solutions will be found or implemented. The National Science Board firmly believes, however, that scientific knowledge and understanding are necessary, and that the steady advancement of science is essential if the potential applications of science are to be realized in the most timely, productive, and economical fashion.

Therefore, the National Science Board begins by stating what it believes to be the basic tenets of United States science policy:

a. The United States will strive to remain competitive at or near the forefront of each of the major areas of science and, to this end, will continue to identify and support scientific excellence.

b. The Nation is committed to the principle that every young person should have the opportunity to pursue advanced education to the extent of his ability and motivation irrespective of geographic origin or economic means.

c. The Federal Government has a responsibility to ensure that new scientific knowledge is utilized as rapidly and effectively as possible in support of national goals and for the welfare of the world's peoples.

The National Science Board supports and commends efforts by the scientific community to address major problems of our society. At the same time, the Board is concerned that scientific endeavors intended to enhance the long-term national future not be sacrificed to the urgencies of the day. Accordingly, the Board recommends that future planning for the total Federal support of science through all agencies strive to be commensurate with the three tenets above.

A clear recognition within the Federal Government that the pursuit of science as a national mission is imperative to the achievement of these ends. The future of the country requires the advancement of science, and the advancement of science explicitly requires the advancement of the physical sciences. Many of the following recommendations, however, do not apply solely to the physical sciences. The more general recommendations are given first.

RECOMMENDATIONS

1. Excellence in science is a national goal and should be explicitly so considered by the National Goals Research Staff. Further, the National Science Board expresses its desire to participate in the preparation of a Government-wide plan for the realization of this national goal.
2. In the continuing process of establishing scientific priorities within the political sector, including actions by the Congress and the Bureau of the Budget, there should be an even greater input by the scientific community through a variety of mechanisms.
3. Within the framework established by the political process, there should be assured support of the best research in the physical sciences and implementation of new ideas and programs of exceptional scientific promise. The potential for increase of fundamental understanding is not only the best criterion of scientific excellence but is also just that feature of science which is most likely to lead to new technology. This principle should continue to play a major part in setting scientific priorities.
4. The Federal Government should expand its programs of institutional and departmental support for graduate education and provide stable levels of support so that academic institutions can afford to take the initiative and make the commitments inherent in educational and research ventures and in supporting young researchers.
5. The United States scientific effort is currently threatened with possible mediocrity. Funding limitations currently imposed by the Federal Government on scientific research should be lifted before the present vitality of the physical sciences, which is essential to the progress of all science, is lost. Support levels in the physical sciences should be made comparable to those recommended in the studies of the Committee on Science and Public Policy of the National Academy of Sciences in the fields of astronomy, chemistry, and physics.
6. The National Science Foundation is the only Federal agency whose primary mission is the advancement of science. Because of this mission, a substantial fraction of the necessary increase in research support should be channeled through the National Science Foundation to provide greater stability and balance to the total national effort and to give the National Science Foundation opportunity for greater initiative in the development of research programs in the physical sciences.
7. All agencies should continue to give special attention to research programs in the physical sciences which support individual investigators and small groups in such fields as chemistry, solid-state science, atomic and molecular physics, and the smaller research projects in astronomy, many of which are now underfunded to the point approaching stultification. These programs, which are highly competitive, of prime scientific and technological significance, and particularly adaptable to the training of graduate students in these fields, make an enormous contribution to the physical sciences and often establish the essential groundwork for larger and more complex efforts. It is ill-advised to fund such programs at a level at which a majority of high-quality proposals must be rejected or underfunded.
8. The acquisition and construction of new instrumentation is the pacing item for research in much of the physical sciences. Radio astronomy alone requires an investment of approximately $200 million in major new facilities in the next ten years. Commensurate efforts must also be made in chemistry, physics, and optical astronomy. Plans for major new facilities should include realistic long-range

plans for operating support, including provision for successive generations of auxiliary instrumentation, and for periodic updating of the equipment. These long-range plans should be consistent with the three- to ten-year period required for the design, construction, and bringing into operation of major facilities.

9. Expensive research facilities, including instrumentation, should be established as national or regional resources. Basic responsibility for the creation and operation of such facilities can be vested in single institutions or in groups of institutions. The pattern of users groups, such as those operating in high-energy physics, should be encouraged to spread throughout the physical sciences. Federal agencies should be prepared to bear part of the added cost of utilization of such facilities as a trade-off against duplicating facilities and expensive instrumentation at additional locations. The importance of first-class resident staffs at all large facilities must not be overlooked. Systems of peer judgments, however, should be employed at such facilities to insure their availability to the best scientists for the most significant experiments.

10. Federal agencies should continue to review older or less productive large facility installations for selective phasing out in order to relieve funds for building and operating new facilities which are closer to the forefront of developments in scientific techniques and capability. Large facilities, both old and new, should be continually supplied with the most modern sensing and data-processing equipment to assure their optimum use. Such modernization is requisite even at the expense of some existing facilities which are still useful.

11. The United States should continue to work for international participation in the planning and utilization of large research facilities, including exchange of scientists and complementarity of programs and equipment.

12. The Department of Defense, along with the other mission-oriented agencies, notably the Atomic Energy Commission, the National Aeronautics and Space Administration, and the National Institutes of Health, should continue to support basic research in all areas of the physical sciences which show reasonable promise of having a bearing on their missions. The National Science Foundation should be provided with funds to assume support for those worthwhile ongoing research programs for which mission-oriented agencies may no longer be able to provide continuing support because of fiscal reasons or change in mission emphasis.

13. The present trend to decrease funding for the scientific aspects of the space program should be reversed. Provisions should also be made for more active participation by academic scientists in these programs, including adequate funding of the academic research groups. Funding must be assured also for supporting research and technology in physics, chemistry, and especially in optical and radio astronomy in order to ensure the greatest scientific payoff from the space capability. It is urgent to upgrade the scientific programs associated with future lunar landings, including the subsequent analyses of mission data and lunar samples.

14. The universities should intensify their efforts to adapt their graduate programs to the changing needs of industry, Government, and the educational system. Special consideration should be given both to the time requirements for the doctorate and to the establishment of "practitioners degrees" at the doctoral level in the physical sciences.

15. Additional and more effective ways should be found for industry, Government, and universities to cooperate in translating basic science into social utility and in opening up for basic research the new areas which are often suggested by technological problems.

16. An effort should be made to utilize more industrial and Government scientists on advisory panels which help select research projects for Federal support and on advisory committees which help develop national science policy.

REFERENCES TO THE TEXT

The following listing contains appropriate references to the text for the several recommendations:

Recommendation 2; pp. 35-38
Recommendation 3; p. 38; pp. 55-56
Recommendation 4; pp. 41-45; "Toward a Public Policy for Graduate Education in the Sciences," National Science Board, 1969
Recommendation 5; pp. 35-45
Recommendation 6; pp. 49-50; p. 54
Recommendation 7; pp. 39-40
Recommendation 8; pp. 39-40; pp. 55-56
Recommendation 9; pp. 51-54
Recommendation 10; p. 52
Recommendation 11; p. 56
Recommendation 12; pp. 49-51; p. 54
Recommendation 13; pp. 56-57
Recommendation 14; pp. 45-47
Recommendation 15; pp. 46-51; pp. 58-60

I

State of the Physical Sciences

In 1969, for the first time, man left the protection of the earth and landed on the moon. Whenever mankind looks back on the history of his achievements, this year will date that banner event. Why can this generation go to the moon when earlier ones could not? The answer is that man has accumulated a sufficient knowledge of the physical universe, an adequate control over the forces of nature, and a suitable technological and industrial enterprise to enable him to build and operate the instruments and vehicles needed. Solid-state computers solve the necessary problems in celestial mechanics and in orbit theory with great rapidity and reliability. The knowledge of how atoms interact with one another to form molecules enables chemists to produce exotic fuels whose reactions give rockets enormous thrusts that can still be delicately controlled. A knowledge of the properties of solids permits the production of materials which will withstand the forces and temperatures to which they are subjected in rockets and other space vehicles. Man's understanding allows him to design space vehicles which pass through the earth's atmosphere at escape speeds and to deal with such potential hazards to the space traveler as the solar wind and magnetic storms. Apollo 11 was, in this sense, a culmination of 400 years of progress in science as well as in technology.

Though man's flight to the moon assures 1969 a place in history, it will have several rivals for the position of the outstanding event of this century. The twentieth century will be known also as that age in which man discovered and learned to use nuclear energy. It will be known as the age in which the physics of the electron was employed to produce a communication system that allowed men to see and hear one another wherever they might be on the earth, or in space beyond the earth, and to produce high-speed computers which enabled men to utilize their brains in the same way that machines have made it possible for them to extend their brawn. It will be known as the age of chemical synthesis, when man, first in the laboratory, then in huge chemical plants, tailored molecules to fit his own purposes by rearranging atoms to produce materials with a variety of useful and pleasing properties undreamed of in earlier times. From these materials have come his clothing and fishing lines, his detergents and lubricants, his medicines, and even his food. It will be known as the time when man eradicated, or brought under control, many of the diseases which had plagued him throughout his history. We hope that the twentieth century may even yet be known as the one in which man finally eradicated hunger, in which he learned to control his population, to conserve his environment, and, most deeply, to live without war.

A. THE UNIVERSE

By 1969 the scientist has done more than demonstrate the application of his science. The vast laboratory of the universe is now more accessible to the scientist, and it presents him with a much extended array of physical and chemical circumstances. The gravitational force is mild on the earth but exceedingly strong near the dense and massive stars. The stars form galaxies and clusters of galaxies, which are the largest systems known to man. Starlight is generated by the interaction of nuclear particles, which are the smallest systems known to man. In the astronomical universe, temperatures range from a few degrees in intergalactic space to billions of degrees in the interior of stars. Densities range from a few atoms per cubic meter in space to more than 10^{15} times the density of ordinary terrestrial materials in neutron stars. Particle energies in the cosmic radiation extend at least to 10^{22} times the energy characteristic of molecules in air at ordinary temperatures. The study of matter and energy under these natural extremes and relating the results to those found in the much narrower range of the earth-bound laboratory are the joint domain of astronomy, physics, and chemistry.

Both in space and on earth, man's ability to observe nature with high precision and under extreme conditions presents the physical scientist with the most critical tests of his theories. The questions he faces are ever more difficult, and the means of answering are ever more complex and subtle. His attempts at understanding may be frustrating. If history is a guide, however, further development of our civilization will depend in part upon his success, and rich

rewards will come to those peoples and nations whose scientists succeed.

Currently there is a scientific explosion in astronomy and astrophysics. The last decade has seen the discovery of "quasars" and "pulsars," X-ray stars and neutron stars, cosmic background radiations and cosmic-gas masers, infrared stars and infrared radiation from many cosmic sources, gamma-ray and neutrino astronomy, transuranic elements in cosmic rays and complex molecules in interstellar matter, and contemporary synthesis in matter ejected from stars. The detection of gravitational radiation from sources outside the earth has been reported. The rapid pace of discovery in astronomy and astrophysics during the last few years has given this field an excitement unsurpassed in any other area of the physical sciences. During the seventeenth century Newton's law of gravitation provided the major influence on the physical sciences. In the nineteenth century Mendeleev's periodic table filled that role. But today the investigation of these many recent major astronomical discoveries may provide a similar influence on the physical sciences. The current significant discoveries in the other physical sciences are, to a large extent, unanticipated consequences of known physcial principles and are fitted into a generally acceptable pattern of theory and experience. The new discoveries in astronomy have presented deeper mysteries and hints of physical processes more unusual than anything observed in the laboratory or predicted by current theory.

1. QUASARS

The discovery in 1963 of quasars created a revolution in the outlook of astronomers. The universe suddenly appeared more violent than had been conceived before. The vast energy production which the quasars appear to show cannot easily be accounted for by presently known energy-producing processes. The spectrum of their light is distorted in a puzzling fashion. Is this distortion due to the expansion of the universe? If so, quasars must be ten times farther away than the farthest galaxies previously observed. Or, does its origin lie in the intense gravitational field around the quasar? Or, is a quasar a much closer object that has been ejected with a speed almost that of light from the interior of a nearby galaxy? Even to approach these questions, one must use

373-722 O - 70 - 2

the viewpoint of Einstein's general theory of relativity. Twenty years ago that theory was regarded as the intellectual culmination of physical theory. Now it is the essential starting point for experiment and observation.

2. RELATIVITY

Our new ability to operate delicate instruments deep in space and our improved techniques for observing astronomical events with ground-based instruments offer us an opportunity to apply definitive experimental tests to the general theory of relativity. These experiments will involve such activities as the precise observation of the motion of extremely stable gyroscopes in earth orbit, refined detection and analysis of gravitational waves, and radar measurements of minute changes in the motion of the planets. Scientists in several United States laboratories are now engaged in the design and development of the sophisticated instrumentation needed for such measurements. Prototypes and test models of individual components are presently being constructed. The actual experiments usually will require very large installations, such as giant radio telescopes, or complicated space missions, as in the case of the gyroscope experiment. But if man is to achieve a fundamental understanding of gravity, such experiments must be done.

3. PULSARS

About two years ago a group of radio astronomers in Great Britain made a startling discovery, a new class of celestial objects that emit short pulses of radio energy at regular intervals of a few seconds or less, called pulsars. Subsequently, United States astronomers found the central star of the Crab Nebula to be a pulsar having all its visible light in the form of pulses coincident with those of its radio pulses and regularly spaced 1/30 second apart. These objects emit enormous amounts of energy, or they would not be observable at all. How could emission of such enormous amounts of energy be interrupted so completely and with such regularity? It now seems likely that the emission is not interrupted but that pulsars are rotating neutron stars which radiate directional radio, optical, and X-radiation beams. They are believed to be the most dense form of matter, compressed to the density of an atomic nucleus in the course of gravitational collapse following supernova explosions. Whereas the sun has a diameter of 864,000 miles, a neutron star with the same mass may have a diameter of only six miles. Since 1950, radio galaxies, quasars, and pulsars have presented man with challenging new phenomena for which no entirely satisfactory explanations are in sight.

4. OBSERVATION AND EXPERIMENTS IN SPACE

Unfortunately, in studying the universe, one cannot experiment in the usual sense. One can only observe; one cannot manipulate or alter the systems being observed because they are so vast and so distant. Observations of the universe, however, do often guide the design and performance of critical experiments on earth. They also frequently demonstrate processes which are useful to man's other purposes. For example, the observation that the apparent lifetime of stars exceed the capacity of then-known fuel supplies led to the inference of the existence of nuclear-energy sources—later identified with the nuclear processes which are a part of our atomic age. Also, the study of cosmic rays which impinge upon the earth from outer space has played a central role in high-energy particle physics over the past forty years and will continue to do so in the future. Many important physical entities—positrons, muons, pions, mesons, lambda particles, and charged hyperons—were discovered in cosmic-ray investigations. Until quite recently the ultimate validity of electromagnetic theory could be investigated only by the use of cosmic-ray particles. The most energetic particles in the universe, produced by processes not yet understood but certainly cosmic in scale, constitute one of the tools we use to unravel the smallest scale phenomena in the universe. There is an inverse relationship between the energy of the bombarding particles used to probe the structure of matter and the scale on which this structure can be resolved—the higher the energy the finer the resolution. Decisions for or against construction of nuclear accelerators larger than those which are now being built may possibly be based on the results of cosmic-ray studies made in space in the early 1970's.

B. THE MICRO-UNIVERSE

Systems that are either very large or very small are frequently the easiest to understand. Man derives inspiration and valuable hints about processes on earth from his study of the universe. His achievements in understanding the universe are closely tied with his ability to understand and manipulate matter with ever increasing precision and on an ever finer scale. Many of our human aspirations for the future depend upon our success in understanding earth-bound systems on a scale intermediate between the very smallest and the very largest. Our probing into the very large and the very small will continue to yield dividends, many unexpected, in the understanding of "people-sized" systems. This will come about both through increased theoretical understanding and through the development of experimental techniques which can later be adapted to different problems. Major contributions to man's ability to control his environment will come from his understanding of matter on the scale of atoms and at energies measured in electron volts. This is the domain of chemistry and of atomic, molecular, and solid-state physics. Furthermore, an increasing contribution will come from our ability to reassemble the results of studies at a molecular scale to bring them to bear on the understanding of systems at a higher level of complexity and organization, such as living organisms, populations, and natural and man-made environmental systems. This synthesis of results at the molecular level to provide an understanding of, and an ability to control, systems at higher levels of organization provides one of the great challenges to chemists, physicists, and engineers. For example, one cannot attack many of the fundamental problems of pollution without new and more delicate methods of chemical and physical analysis and without further elucidation of processes which produce pollution. Also, one cannot understand and predict the effect of trace impurities on human health and on the biosphere without deeper understanding of the biochemical processes in which they participate.

1. CHEMICAL SYNTHESIS

The vast array of manmade materials produced by the manipulation of molecules might lead one to believe that synthetic chemistry now constitutes an essentially complete system of knowledge. But such is not the case and much research remains to be done. For example, an important contribution to the problem of water pollution arises from the accumulation of synthetic detergents in our river systems. Some detergent molecules accumulate because they are not subject to degradation by micro-organisms in the water. Subtle changes in structure needed to make detergents biodegradable are now understood, but synthetic methods of producing the desired substances from economically attractive raw materials are not now known. In other problem areas progress is slow because structural modification of molecules is still something of a hit-or-miss affair, not because of obvious deficiencies in the synthetic methods, but because current theories relating chemical structure to material properties are not adequate to provide guidance.

Other synthetic materials hold promise for the future and will become productive as synthetic methods and theory relating structure to properties are further developed. For example, we ought to be able to produce synthetic materials with electrical conductivity equal to that of metals. Imagine the production of nylon-like fibers, finishing lacquers, and sheets of tough, pliable film having conductivity similar to that of copper or aluminum. Some might even display the remarkable characteristic of superconductivity. The range of new and useful electrical devices that could be fabricated from such new conducting materials defies imagination.

The prospect that chemical synthesis can and will produce more and more new substances having properties that will sustain, ease, and ornament men's lives is attractive, but a note of reservation is needed. We have not yet arrived at the point where it is always feasible to produce on demand a material having a desired property. Two further steps are needed to accomplish this objective. First, there must be an improved theory relating the properties of materials to their chemical structure. Second, there must be an economically attractive chemical path from available raw material to the desired end product. In general, satisfying either requirement cannot be guaranteed. Though much can be accomplished with the guidance of current theory or by trial-and-error methods, the potential payoff from deeper understanding is great. Such understanding offers more rapid and economical solutions less liable to unexpected side effects.

The preparation of new agents in medicine has been substantially expedited by recent developments in the methods of synthesis. New antibiotics such as modified penicillins are being produced by synthesis rather than by bacterial fermentation. The goal is to obtain compounds with lower toxicity and with greater selectivity against bacteria or with activity against a broader range of bacteria, or with activity against types of bacteria that have grown resistant to currently available antibiotics. Synthetic sex attractants make possible the elimination of particular species of insects, for example the cabbage looper, without the hazards to other forms of life inherent in broad spectrum agents. The present version of the "pill" depended heavily upon the development of new methods of synthesis and upon the availability of analytical instrumentation. Although better understanding of the social sciences is crucially involved, the chemical regulation of fertility by the use of synthetic compounds will greatly ease and facilitate the social engineering involved in limiting the human population.

2. CHEMICAL DYNAMICS

Chemical dynamics is the science of chemical change and complements structural chemistry. Structural chemistry deals with the static molecular organization of matter, and dynamics introduces time as an important molecular property. The dynamicist is concerned with the probability that one chemical structure will change into another and how rapidly these changes occur.

Chemical reactions occur with many and varied characteristics. Some reactions such as combustion processes release energy, while others can absorb and store energy supplied as heat, light, or electricity, as in storage batteries. Some reactions occur so rapidly that the average lifetime of molecules in a reacting system is a billionth of a second or less; other reactions occur so slowly that they cannot be observed easily during the life span of a man. The slowness of slow reactions arises from the time required for molecules to prepare for final action. These preparations may include the gathering together of partners for a reaction, the accumulation of some minimum energy content, or concentration of energy in just the right molecular vibrations to break existing bonds and form new chemical bonds between atoms. Furthermore, subtle changes in reaction conditions such as the presence of a catalyst often lead to enormous changes in reaction rates. Understanding and control of the rates of chemical reactions is a monumental task because it is necessary to work entirely with theoretical models and indirect evidence.

There are several reasons for expecting an acceleration of progress in chemical dynamics. Only recently have concepts clarified to the point where they could serve as the stimulus for definitive experiments. Two things had to happen before much real progress could occur in the application of quantum mechanics to the understanding of reactions. First, the complexity of the paths or mechanisms of many reactions had to be realized and at least partially understood. Second, experimental methods for the study of elementary reactions had to be found. Many processes do not occur in a single step but consist of a series of definable chemical reactions. One of the great accomplishments of the past four decades has been the dissection of many such complex reactions. The understanding of the molecular basis of visual excitation is a current example. As mechanistic analysis of such reactions has progressed, some puzzling facts concerning chemical reactivity have started to fall into place. Thirty years ago the literature was full of curious examples of compounds having seemingly similar structures that showed enormous differences in reaction rates. Many such differences now appear reasonable and systematic because careful consideration of the steps in a reaction has shown that small structural changes have a profound influence on the reaction rate in a key step.

Chemical physicists now have the tools for investigating the simplest reactions. In experiments with molecular beams, they can aim reactive molecules having known energy content at other molecules and measure the results from single collisions. The few systems that have been studied in this manner are so simple chemically that the results are of little immediate use to chemists working with the complex chemical substances of biochemistry and chemical industry. However, new experiments with molecular beams are being designed. When they can be carried out, giant steps will be taken in bridging the gap between understanding the simplest reactions and understanding the more complex ones of practical chemistry.

A final ingredient needed to set the stage for rapid advance in chemical dynamics is the development of better theory. By comparison with the progress of theory in structural chemistry, the theory of chemical dynamics has moved at a snail's pace during the past few decades. Fundamental, directly relevant, experimental data of static chemical structures are more readily available than are data relating to chemical dynamics. However, experiments with elementary reactions, including processes as simple as the collision of electrons with atoms and molecules, are providing the basis for a new generation of general chemical-rate theory. At the same time, there is a surge of interest in the special information to be gained from the chemical behavior of energy-rich species. Photo-chemistry, the study of reactions induced by absorption of light, is the principal focus of activity, but a number of other ingenious methods have been devised for production of highly excited atoms and molecules. The results show that chemical reactivity may depend strongly on the energy of a molecule. The demand for expansion of the scope of reaction-rate theory is causing an encouraging reevaluation of the entire field.

Control of chemical changes provides us with opportunities to control ourselves and our environment. Life depends upon near-perfect synchronization of thousands of continuous chemical reactions occurring in living organisms. Controlled chemical change is also incorporated in many manmade systems. An example is the combustion of gasoline in an automobile engine. The process is useful because it allows self-portable conversion of chemical energy to mechanical energy, but it is also crude and dirty because combustion of the fuel leads to noxious atmospheric pollutants. The modern automobile is a marvel of mechanical engineering but uses chemical processes that are as primitive as touching a match to dry kindling. This incongruity of the automobile is repeated over and over again in manmade devices. Mechanical and electrical designs are far advanced in comparison with the design of working chemical units in many of the machines that we invent. In order to upgrade the chemical components of engineered systems, we must depend upon increasing knowledge of chemical dynamics to make possible a kind of chemical systems analysis far more sophisticated than we now have.

3. SOLID-STATE SCIENCE

Solid-state science has been especially fruitful in discoveries and concepts which are of both fundamental scientific importance and readily applicable to technology. This study of the behavior of atoms, electrons, and energy in solids is currently one of the most productive activities in science and is an outstanding example of the beneficial mixing of the disciplines of chemistry and physics. Experiments and theories about various types of imperfections in solids have revolutionized thinking about the mechanical properties of materials. A wide variety of techniques enables the electronic structure of metals, semiconductors, and insulators to be determined in extraordinary detail.

Consider the use in science and technology of the newly found understanding of just one single phenomenon in solids; namely, superconductivity. One of the more obvious future applications of superconductivity is in power transmission. The power loss in a superconducting transmission line would be zero because the electrical resistance of a superconductor is zero. Superconductivity, however, has been demonstrated only at very low temperatures. Power transmission by superconductors will become commercially attractive when the savings on power loss exceed the cost of refrigeration of the line. The continuing development of superconducting alloys with higher working temperatures provides hope that the economic crossover may occur in the near future, thus allowing economic long-line transmission of power from distant hydroelectric or nuclear plants.

A contemporary application of superconductivity is its use in very high-field electromagnets. One use of such magnets is in plasma containment, a key problem in the development of a controlled thermonuclear reaction. The most likely way to contain such a high-temperature plasma is in a magnetic field of suitable design. A conventional electromagnet consumes power; a superconducting electromagnet does not. Unless strong magnetic fields can be generated with negligible power consumption, the thermonuclear reactor will consume most, if not all, of the power it produces. There is also hope of containing such plasmas in radio-frequency resonant cavities. For the radio-frequency fields to be high enough to contain thermonuclear plasmas economically, the walls of the resonant cavities must be superconducting.

Any or all of these developments may make it possible for the country to move in socially as well as economically desirable directions. The very remoteness of major power plants, the diminished fuel requirement, the absence of effluent, and the burial of transmission lines would each contribute to an improved quality of the environment.

A device which rests heavily on the fundamental theory of superconductivity is the Josephson junction. Among many uses, it can be employed as a voltmeter which will measure electrical potentials to a precision a hundred thousand times greater than that of any conventional voltage-measuring device. Most electrical measurements can be turned into a voltage measurement. Consequently, all such measurements may, in principle, enjoy a corresponding improvement in precision, which will have many uses in scientific instrumentation and other technology.

These are but examples of applications of superconductivity that are ahead. Similar examples could be given of applications of many other phenomena which research in solid-state science is bringing into the realm of our understanding.

4. ATOMIC AND NUCLEAR SCIENCE

Atomic physics has experienced a remarkable upsurge in activity in the past few years. In university, industrial, and Government laboratories, where atomic studies had become practically dormant, lively research has now been revived. The achievements include redetermination of fundamental constants with greatly increased accuracy and precision, the development of laser beams and atomic clocks, and the increased understanding and control of plasmas. All of this has expanded the interface between atomic physics and other fields—chemistry, engineering, solid-state science, optics, geophysics, meteorology, and astronomy.

Nuclear energy for military purposes has been of critical importance for twenty-five years. However, nuclear energy has just become economically competitive in our rapidly expanding civilian power industry. Last year more than fifty percent of all electrical generating capacity contracted for in the United States was nuclear powered. Reactor experts are confident that nuclear power plants can be designed to produce power at still lower costs; but to do so, more accurate basic physical data will be needed. Improved theory of nuclear reactions will also help provide for a more extensive theoretical exploration of alternative designs. We can anticipate significant economies in design procedure as well as more efficient designs in terms of power cost. The economic impact of even small reductions in power cost will be tremendous. For example, if the price of electrical energy can be sufficiently reduced, magnesium production will be competitive with that of aluminum, thereby giving aluminum its first competitor for an economical, light, strong metal.

One of the most dramatic consequences of the coming of age of large nuclear power complexes could be the impact on hunger and poverty throughout the world. For the first time mankind can be divorced from nature's caprices in providing natural energy sources, such as waterfalls and fossil fuels, often where they are least needed by civilization. A test nuclear power complex now under study will produce, along with 1,000 megawatts of electrical power, twice the output of ammonia and phosphorus of the largest fertilizer factory now in operation in the United States. Such a plant by itself would supply the fertilizer need for an agricultural operation sufficient to feed more than two million persons.

Radioactive tracer techniques have provided a research probe of great capability and have helped make possible an entirely new level of understanding of biological phenomena at the molecular and cellular levels. Clinical use of radioisotopes and radiation sources in the control and treatment of cancer is extensive. Much of the electronic instrumentation for medicine originated in nuclear physics. Techniques involving nuclear phenomena, such as the Mössbauer effect, neutron diffraction, and neutrography for soft-tissue studies, are now being assimilated by the medical profession.

In the last two years experiments in nuclear physics have become more elaborate and more precise. This progress in experimental nuclear physics has been matched by advances in nuclear theory. The wave of theoretical and experimental advances is quite startling to those who thought the field had passed its peak of interest. New particle detectors permit measurements, which heretofore required months, to be made in a few hours. New accelerators, including large tandem Van de Graaffs, sector-focusing cyclotrons, and high-intensity electron linear accelerators, have laid open for the first time the entire periodic table of the elements to precise investigation. Utilization of highly developed electronic instrumentation in conjunction with on-line computer control has allowed nuclear physicists to attack vital and central problems of nuclear structure which had previously been beyond their capabilities. Beams of electrons and heavier charged particles from the newer high-energy accelerators provide effective probes for studying hitherto inaccessible phenomena in the interior of the nucleus.

Accelerators have found widespread applications in other fields of science. Using beam-foil techniques, it is possible to produce highly excited atomic ions and to study the transition rates between pairs of excited states. The results are of crucial importance in atomic physics and astrophysics, especially in the interpretation of the spectra of quasars. Properly directed ion-beams are "channeled" through solids with exceptionally low energy losses and can be used to probe crystal structure and to locate the position of impurities in crystals. Ion implantation has given solid-state science a new tool of many uses. Accelerators have long been used in studies of the rates of those nuclear reactions which generate energy and synthesize new elements in stars. There has been a great upsurge in measurements on the light nuclei in recent years in connection with attempts to detect neutrinos from the sun. It is now clear that the interactions of intermediate and heavy nuclei must be studied with great detail and precision before the advanced stages of stellar evolution can be understood. This is particularly true in regard to the final implosion-explosion stages which result in supernovae and even more violent astronomical events.

The high-energy accelerator can also be made to produce a copious beam of negative pions for cancer therapy. Such particles are uniquely suited for this purpose. The range of pion beams is so well defined that the lethal heavy-particle radiation resulting from their capture by atomic nuclei may be localized in the tumor. It is believed that the advent of superconducting linear accelerators will permit the development of therapeutic pion sources whose cost and size will be sufficiently small to allow construction of such machines in all major hospitals and cancer treatment centers.

In the last few years, nuclear physics has become a qualitatively different field as vaguely perceived ideas concerning nuclear structure and behavior have come into sharper focus. The nucleus is a microcosm spanning many forces and laws of the universe. Nuclear science, both in physics and in chemistry, has provided a treasure house of new phenomena and is increasingly a versatile servant of science and society.

5. ELEMENTARY PARTICLES AND HIGH-ENERGY PHYSICS

The frontiers of modern physical science range from the domain of the very large to the domain of the very small. Just as astronomy and astrophysics probe the former so do elementary-particle and high-energy physics probe the latter. The exciting advances in one are matched by those in the other. The results insure progress in mankind's understanding of the universe on its grandest scale and on its most fundamental scale. Without the one, the understanding is mundane and parochial; without the other, it is shallow and empirical.

High-energy physics attempts to establish the fundamental laws of matter. It searches for the laws governing the four fundamental interactions—strong nuclear, electromagnetic, weak nuclear and gravitational. In this search, high-energy physics has found new features of natural laws, such as the violation of parity or "mirror symmetry" and the asymmetry between matter and antimatter or violation of "charge symmetry." Apart from seeking an understanding of the interactions between the basic units of matter and antimatter, high-energy physics seeks to find the reasons for the existence of the particles themselves. Why do atoms consist of nuclei and electrons? Why do nuclei consist of nucleons—neutrons and protons? Why do nucleons have structure? More importantly, do these subhierarchies adequately describe the physics of the very small? What about the other worlds beyond the microscope where modern accelerators have exposed neutrinos, the chargeless sisters of electrons; the mesons, messengers of the nuclear force in mimicry of the photon's role in electromagnetism; and the baryons, higher states, with rich and varied properties, of the neutron and proton? Even the nomenclature recalls our ancient traditions of knowledge—the twin neutrinos and electrons, interacting only through the weak nuclear force, are called leptons, the mesons and baryons, paired in the strong nuclear interaction, are called hadrons.

In this field, experiment and observation dictate the pace of discovery. Theory is hard put to accommodate and assimilate, but it has succeeded in codifying in a simple and elegant way the rich spectra of the hadrons. Triumphs of the theory have been the prediction and subsequent discovery of new particles once the underlying classification was understood.

An exciting sequence began when cosmic-ray observers discovered some very strange particles which experimenters at high-energy accelerators subsequently produced. The puzzle about these particles was that, although they were copiously produced and decayed into particles which were known to interact strongly, they lived amazingly long compared to the lifetime expected for such particles. The solution was simple. The "strange" particles, as they were dubbed, were always produced in pairs and could then interact strongly; but in decaying, which they do singly, they interact very weakly. But there was an additional puzzle. Although production of mesons or baryons in pairs seemed understood, the production of a baryon simultaneously with a meson seemed "strange." This led to a clear recognition of "strangeness" as a new quantum number. Whether we liked it or not or whether we understood it in terms of current reality or not, there was a new law of physics in the record books—"strangeness" is conserved in the strong nuclear interaction and is violated in the weak nuclear interaction for which the characteristic interaction time is relatively long.

The weak nuclear interaction moved to center stage. The definitive tests are not yet complete, but it is probably a universal interaction applying to all the hadrons and leptons. It is especially important in lepton physics, because leptons do not share in the strong nuclear interaction. One of the most exciting discoveries in physics in recent years concerned these leptons. Charged leptons occur in four forms—negative electrons and positive electrons (positrons), negative muons and positive muons. The discovery followed the dictates of symmetry—experimenters found neutrinos and antineutrinos which always paired with electrons and positrons and completely independent twins which always paired

with the two muons. There exist electron neutrinos and antineutrinos, and there exist muon neutrinos and antineutrinos.

The symmetry of the weak interactions stopped there. Theory surmised and experiment showed that electrons spinning relative to their motion in the sense of a right-handed screw thread did not behave identically with their left-handed brothers. This seemed to violate the mirror symmetry of physical laws, since left-handedness transforms to right-handedness on mirroring. Why should the laws of physics be different for the image than for the object? The situation was saved by the experimental discovery that right-handed positrons behaved like left-handed electrons and vice versa. This resulted in a great measure of general satisfaction that physical laws were invariant to the combined operations of mirroring, parity and charge, and matter-antimatter exchange.

For all men, symmetry, even in the sophisticated form evidenced by the weak interactions, is a thing of beauty and conceptual usefulness. There is a strong theme of symmetry in all approaches to scientific understanding—from Newton's action and reaction to Dirac's matter and antimatter. In this respect high-energy physics brought us to a crossroads in our basic understanding of nature. The surprising discovery was made that the continued symmetry operation of replacing particle by antiparticle and of mirror reflection is not a perfect symmetry of nature. A certain type of meson broke these symmetry rules. No other such violations have been found. The clarification of this phenomenon is one of the great challenges facing particle physics. Charge-parity violation implies that certain natural processes are no longer invariant to time reversal. We believe intuitively that the physics would not change were the earth to stop and instantly reverse its motion around the sun. Is this not true in the world beyond the microscope? It is to high-energy physics with its preoccupation with the smallest units of matter that we must look for the answer.

Concern for symmetries in our descriptions of the laws of nature is not new. Over the centuries it has been believed that the appearance of symmetries was one of the most fundamental aspects of nature. Upon several occasions in the past, however, experimental results have led scientists to abandon their intuitive ideas and to discard certain symmetry principles. Eventually, however, a way would be found to reformulate a part of basic theory so that those symmetries were restored. In each case the new insight into nature thus gained opened for exploration new areas of science and technology. For example, the cruder work of Copernicus, Galileo, and Kepler preceded Newton's formulation of the basic laws of dynamics and expression of the gravitational law in a mathematically symmetrical form. Today this theory can be used to explain the motion of everything affected by gravity, from baseballs to satellites. The laws of electromagnetism required over a century for their gradual refinement, and the search by Maxwell for a mathematically symmetrical treatment of electric and magnetic forces was an essential element in their perfection. These laws now permit the understanding of all electromagnetic radiation, including light, and the development of radio, television, radar, and computers. Concern for the symmetrical treatment of space and time played a crucial role in Einstein's development of the theory of relativity and produced in the process the essential key to the release of atomic energy.

The concept of symmetry, therefore, has been too fruitful to be abandoned lightly. It is, of course, possible that nature is really not symmetrical. However, experience indicates that it is worth man's effort to try to find fundamental errors or omissions in his description of nature whose correction or inclusion might retain symmetry. The history of science, indeed, leads the scientist to suspect that a key to new levels of understanding nature, and thereby to improved technology, lies hidden in the debris of apparently broken symmetries.

II

Nature of the Physical Sciences Enterprise

A. UNITY OF SCIENCE

In recent years the development of the physical sciences has been characterized by a rapidly increasing degree of unity in concepts, models, and experimental techniques. Modern chemistry, for example, uses concepts and theories originally evolved in physics. Conversely, many physical concepts themselves could not have been fully developed without information and generalizations transferred to physics from chemistry. Astronomy has also shared in this unification of the physical sciences. Not only have physical effects seen in the laboratory been shown to have counterparts in the stars and in interstellar space, but also the universe itself provides a laboratory in which the behavior of matter can be studied under extreme physical conditions not attainable on earth. There is, indeed, a large common area among chemistry, physics, and astronomy, where research interests strongly overlap and where the difference is more in style and perspective than in subject matter.

In general, the physicist is most interested in finding "simple" systems with which to test theories or models he is trying to develop or to verify. While the chemist is also interested in studying systems which illustrate principles and theories, he tends to be more concerned than the physicist with the large variety in the forms of organization of matter and with different instances of general principles. Traditionally, physicists have concentrated their interest in molecules to those containing only a few atoms in order to understand with high precision the quantitative relationship between molecular properties and the basic postulates of quantum theory. Even this distinction in style and approach between the fields of chemistry and physics has largely disappeared since many chemists are deeply involved in molecular theory. Moreover, those physicists who enter the field of biophysics soon discover the special fascination that comes from the study of large molecules in a complex environment. The underlying conceptual unity of physics and chemistry is now extending rapidly into the study of biological systems, and it is becoming increasingly possible to understand the functioning of biological structures in terms of the models and the principles of physics and chemistry.

The natural sciences are approaching a single conception of the organization and structure of matter at varying levels of complexity. The physicist is concerned primarily with atoms and subatomic particles. The chemist deals with atoms as they form millions of different molecules. The biologist in turn deals with tens of millions of species, each one a unique organization of matter.

The trend toward conceptual unification of physics, chemistry, and biology has a counterpart in experimentation and instrumentation. Physical techniques are increasingly used to measure and characterize chemical and biological systems ranging from such simple physical properties as density, viscosity, thermal and electrical conductivity to the more complex areas of optical spectroscopy, electron microscopy, X-ray structure analysis, and magnetic resonance. This extension of physics instrumentation into biology and chemistry is not a one-way street. In fact the application of physics instruments in these fields has often led to their improvement and refinement and has greatly stimulated their engineering development for routine use. For example, the use of X-rays for analysis of crystal structure, originated by physicists and refined by chemists, has made possible the analysis of the structure of molecules of biological interest containing thousands of atoms and resulted in improved X-ray instrumentation. Furthermore, chemical analysis and methods of purification and characterization of materials are necessary preludes to precise and reproducible studies of their physical properties or of the physical processes going on in them.

The unity of the physical and, to an increasing extent, the biological sciences involves also the expanding use of mathematics as a common language among all the fields. This trend has been reinforced by the advent of the high-speed computer, which has made it possible to work with realistic mathematical models of physical systems and to predict their properties and behavior from a few simple, general assumptions applicable to all matter. The computer is also an indispensable tool for analysis of very complex systems in which many closely related changes occur both at the same time and in sequence, as in chemical synthesis.

Astronomy has been able to demonstrate a type of homogeneity of the universe; the laws of behavior and organization of matter and energy seem to be everywhere essentially the same. This idea in turn has become a working hypothesis of enormous power for further exploration. Low-energy nuclear physics has provided a key for understanding the origin of the elements and the evolution of stars. Space probes in combination with our ability to detect radiation in various parts of the electromagnetic spectrum, with high sensitivity, using laboratory techniques developed in physics and electrical engineering, have opened up new windows on the universe and provided clues to physical processes going on in the depths of space.

An important aspect of this unity in the physical sciences is their mutual dependence and reinforcement. We cannot expect to advance too selectively either in the sciences themselves or in the derived technology. Too much selectivity results in missed opportunities and missed clues to important discoveries or measuring techniques. When opportunities, technological or scientific, are opened up by a new discovery, their exploitation can often be planned or programmed, but the discoveries themselves are seldom the result of such a planned development.

Too much selectivity also may leave us without the necessary foundation on which to build new and needed fields of science and technology. For example, our hopes for an early achievement of controlled thermonuclear power were largely dashed by our lack of prior knowledge of plasmas. This principle of broad advance applies to all sciences, but especially to the physical sciences where the structure of technique and understanding is so tightly meshed.

B. TWO-WAY INTERACTION BETWEEN SCIENCE AND TECHNOLOGY

Technology and science reinforce each other in a complex, two-way interaction. For example, the modern computer would not have been possible without many important recent developments in solid-state physics, but our understanding of the structure, properties, and processes of solids has been immeasurably increased by the ability of the digital computer to carry out complex calculations of electronic structure. The computer contains applications of high-speed circuit techniques developed first for the purposes of nuclear physics. In turn the computer is a powerful tool for the automatic selection, processing, and presentation of nuclear data, thereby making possible the study of extremely rare nuclear events. Now the sophisticated data-processing methods developed for nuclear physics are finding application in other areas of computer use which involve the recognition of coherent patterns in a very complex and often apparently random assortment of information.

Solid-state science and metallurgy have made possible the superconducting magnet, which has subsequently found application as an essential research tool in solid-state physics and plasma physics, and has brought closer the realization of controlled thermonuclear fusion in the laboratory. Chemistry in general is an especially fruitful area for the rapid transfer of new information from science to technology. Laboratory studies of chemical reactivity are necessary for the design and operation of chemical plants and for the development of the field of petroleum technology. Moreover, it is now becoming apparent that many of the unanticipated environmental problems created by technology may be stated as chemical problems. Environmental pollution in particular may be understood in terms familiar to the chemist and chemical engineer, and a large amount of relevant chemical information already exists for use in seeking solutions to this complex social and economic problem.

C. CONNECTIONS BETWEEN ESOTERIC CONCEPTS AND PRACTICAL APPLICATIONS

The development of the transistor and nuclear power has particularly dramatized the connections between apparently abstract physical theories and practical applications. Theories are frequently generated by consideration of problems that seem impossibly remote from the concerns of social man. However, the conviction of scientists that a viable theory must be widely relevant provides powerful guidance for application. Such theories often provide the only language and concepts in terms of which new inventions can be made. It is only when these theories become part of the common intellectual coinage of a large number of scientists and engineers that continuing invention in such fields becomes possible. The evolution of solid-state electronics is a testimonial to this fact. Its practical development required the adjustment by engineers and production people to an entirely new scientific environment in less than a single professional generation. What applies to technology often applies equally to other disciplines. For example, the ability to understand and measure radioactivity has revolutionized archaeology by making it possible to date more precisely human artifacts and other remains. A highly sophisticated experiment in elementary-particle physics is now being used in an attempt to locate additional tombs and chambers in an Egyptian pyramid. Similarly, concepts of chemical dynamics developed from the study of small molecules now provide understanding of the mechanisms of enzymatic action in controlling the chemistry of life.

D. IMPORTANCE OF NEW IDEAS AND NEW INSTRUMENTS

New concepts and principles, new physical processes and models, and new measuring techniques which extend precision and sensitivity are extremely important to the development of the physical sciences. Many such advances in technique open up whole new areas of research involving unanticipated phenomena. These advances occur with surprising frequency even in areas of science which are supposedly well understood. Often such developments have the character of being obvious and logical in retrospect. A good example is the Mössbauer effect, recoilless gamma-ray emission by atomic nuclei in crystals, which was implicit in a theoretical paper by Lamb in 1939 but not developed experimentally or even appreciated until 1957. Since its discovery, however, the Mössbauer effect has rapidly evolved as a new tool for investigations in solid-state science, biology, and even in medical practice.

The extension of the extremes of environment—very high or very low temperatures, very high or very low pressures, very high magnetic fields or field-free regions—is also an important tool for advancing science. Often these extensions of the experimental conditions permit study of entirely new classes of phenomena. The exploitation of such capabilities is essential to the continued progress and vigor of the physical sciences even when the precise usefulness of a new technique cannot be predicted or fully understood at the outset.

It is also important to the advance of science that new laboratory techniques be engineered into instruments which can be used by scientists less specialized than the inventors. The development of a practical and relatively inexpensive helium liquefier in the 1940's by Collins in collaboration with Arthur D. Little, Inc., had an enormous influence on the progress of solid-state science by making low temperatures readily available to physicists and chemists who did not have the time or resources to develop their own low-temperature equipment. Similarly the commercial development of the electrostatic accelerator, the mass spectrometer, the nuclear-resonance spectrometer, the electron microscope, high-pressure equipment, and hundreds of other instruments, initially handmade with great travail by laboratory scientists, has permitted researchers to concentrate on the scientific questions rather than on merely reproducing research technologies already pioneered by others. The rapid commercialization of laboratory techniques and instruments has generated a new style of research in which the United States has been in the lead. It has been made possible by the quality and scale of United States research activity, the magnitude of Federal development programs, and the entrepreneurship of our industry.

E. PRODUCTIVE IDEAS AND THEMES

New theoretical concepts and ideas, developed in the physical sciences originally for a rather restricted purpose or for the explanation of a specialized phenomenon, often are productive in an unexpectedly broad range of situations. An illustration of this situation is the theory of superconductivity developed by Bardeen, Cooper, and Schrieffer in 1958. This idea has altered our whole perspective on solid-state physics and has had an important influence on the development of ideas about nuclear structure. It has given theoreticians a tool for integrating the collective and individual particle descriptions of both the behavior of electrons in crystals and the behavior of neutrons and protons in nuclear matter—descriptions which seemed mutually contradictory and yet which were each required for the explanation of different properties.

The concept of particle tunneling, that is, the possibility of a particle penetrating a classically impenetrable barrier, has been a similarly fruitful idea. This idea was initially advanced in the 1930's to explain the disintegration of atomic nuclei. In the last few years it has led to the invention of a new electronic device, the tunnel diode, which has become an important component of computers as a very high-speed switch. The invention of the tunnel diode and its immediate practical application caused a great increase in research on electron tunneling generally. This quickly led to a new technique for fundamental studies of the electronic structure of metals and superconductors. These studies in turn resulted in the prediction and discovery of new types of phenomena involving quantum effects on a scale large enough to permit the engineering of new devices. Because of the tight interweaving of the physical sciences, specific ideas or techniques, developed at first for a particular purpose, turn out to have an extremely productive generalizability.

F. ECONOMY OF THOUGHT

Much has been written and said about the information explosion in science. Certainly, knowledge has increased tremendously in recent years as research data have poured from the laboratories. It is, however, characteristic of the advance of science that, as understanding increases, descriptions of nature can be simplified so that the advance of science is accompanied by information compression as well as explosion. The aim of scientific effort is not information *per se* but rather understanding and insight, and it is this insight which enables us to describe a wide range of observations and experiments by a simple physical model from which much can be deduced. The law of gravitation, as formulated by Newton, replaced the more complex descriptions of the Ptolemaic epicycles and of Kepler's laws. The laws of quantum theory brought much of physics and virtually all of chemistry within a single framework of basic assumptions. In both cases complexity in physical description was replaced by descriptive simplicity and computational complexity. The latter is being brought under control by developments in mathematics and more recently in computers.

Often the new physical description seemed incomprehensible and esoteric, but scientists, by their persistent drive toward generalization, make it become a part of their common intuition, almost a part of the subconscious processes by which they think about the world. When we can use the same concepts to describe processes in the interiors of stars and in the laboratories on earth, a great economy of thought is involved. Such encapsulation of knowledge is often essential for the rapid development of technology. It also permits more informed decision-making with respect to alternative paths which are involved in technological development.

G. MEASUREMENT, DESCRIPTION, AND CONTROL

In the physical sciences the scientific process may be thought of in terms of three operations: measurement, description, and control. Measurement consists of the extension of the sensitivity and accuracy of the human senses by physical instruments. Measurement can be divided into two subcategories, observation and experimentation. In the observational sciences all that man can do is to observe and use instruments. Astronomy is the classic example of an observational science; man can observe the universe but cannot alter it. In an experimental science man not only observes and uses instruments to extend his senses, but, also has an opportunity to alter or prepare the situation which he is observing. Experimentation also helps to develop instrumentation which can then be used effectively in the purely observational sciences.

The next important aspect of science is description. Observation and experimentation by themselves are virtually meaningless without a conceptual framework or context within which to fit what is observed. Theoretical models of even tiny pieces of the universe provide the context without which observation would present a meaningless and chaotic pattern. Man cannot "observe" entities like electrons or atoms without at least a tentative model of what he thinks they are, how they behave, and how they interact with instruments. The process of description thus includes the development of abstract models, and it is the correspondence of these abstract models to reality which in fact comprises the description. Theory also helps to suggest which new observations are likely to be most important. Sometimes the observations cannot be fitted into the context. It is at such critical times when the pattern of observation and experiment becomes sufficiently disjointed from the context that new exciting theories are born.

The use of experiments, in which one controls the situation being observed, is a large step towards the first stage of the engineering process: the control of nature for a purpose other than observation and understanding. The fact that experiments involve control of nature shows why the progress of science, especially in the physical sciences, is so intimately related to the progress of technology. The instrument which one uses for analyzing the chemical composition of a substance being studied in the laboratory can become the instrument for controlling the composition of the constituents in a chemical process for the production of useful materials. Increased ability to control environment in an experimental situation becomes increased ability to control environment for other useful purposes. Most industrial instruments, controls, and processes have evolved from the research laboratory, and such evolution will surely continue.

H. COMMUNICATION SYSTEM OF SCIENCE

The communication processes of science are in some ways quite different from those in many other human activities. Science usually progresses through integration of the results of the apparently isolated activities of hundreds of individual scientists, each concerned with a narrow problem of his own choosing. Yet there is an elaborate and highly developed system of control which turns a mass of interrelated activities into a coherent process. Science is a social process of great sophistication and complexity, and much of its decision-making is highly decentralized. The social process of science is efficient for the progress and advance of scientific knowledge, much more efficient than a highly centralized process could ever be for this purpose. The understanding by the practitioner of this social system of science is an important part of the process of training for research. Because the understanding of this social system of science is taught by implicit indoctrination rather than by explicit instruction, it is often not well understood outside the scientific community.

It is an oversimplification and even incorrect to say that science cannot be planned. The major problem in such planning is the proper differentiation between those decisions which must be made centrally and collectively and those decisions which must be made on a highly decentralized basis. In general the centrally made decisions are those which allocate resources to major programs. In the pursuit of any research project there are many decisions which must be made on a highly decentralized basis. However, competition within the social system of science gives those decisions a value which insures the effective exploitation of the centrally made decisions.

When the country decides to build a major new accelerator, the country is planning to conduct a series of experiments requiring the characteristics of that particular accelerator. This does not mean, however, that the precise experimental program to be conducted with the accelerator has to be planned in advance. The experimental program, indeed, can only be developed as the science develops. Each new experiment depends to an extent on all experiments which have gone before, not only those done with a particular accelerator but those done with all other accelerators all over the world. The planning of any given experiment can only take place in the context of all the knowledge and understanding existing at a particular time. If it takes place in a narrower context, the research becomes inefficient. Detailed experiments planned too far in advance will also be inefficient because relevant new information will appear before the experiment is actually done. Similarly, when the country decides not to build a major new radio telescope, the country is planning not to conduct any observations requiring the characteristics of that particular telescope. The exact program which is thereby foregone cannot be specified in detail; one never really knows what is being given up.

Such mixed systems, which have both a highly centralized or collective component as well as a highly decentralized or individual component, appear in other parts of society as well. In industry the central, corporate management of Company X may decide that the timely introduction of a new product requires the construction of a new plant at Site Y. Many studies are made before and during the decision-making, planning, and construction processes. However, the labor force is not hired before the plant is built. In the final analysis each worker, individually, decides whether he will work for Company X or some other company. That is the essence of decentralized decision-making. But Company X, based on its analyses, makes a highly centralized decision, confident that it can recruit an able labor force.

Similarly we can plan centrally and collectively for the progress of science. We could plan centrally and collectively for the stagnation of science. However, the process of planning in science at the level of detail equivalent to the employment decision of the individual industrial worker, that is, the exact nature of the next experiment, has to be carried out in the last analysis by each research group working in the context of existing knowledge. The able scientist senses the intellectual market for his idea or experiment much as the able businessman senses the economic market for his product. The most relevant question to ask about scientific planning at this level of detail is whether the decisions of particular research groups were made with full cognizance of the existing state of the art and whether their record of planning has been productive in the past. It is for this reason that the planning process in science must continue to contain this highly important, individual, competitive component. The man who is planning his experiment or his calculation is ideally the best person in the world to plan that particular experiment or calculation. The entire social system of science and its system of sanctions and rewards press him to be aware of all the work in the whole world which is relevant to his particular experiment or calculation.

The ideal is never fully realized in practice, but the reality is sufficiently close to the ideal to make the social system of science highly efficient in achieving its goals of insight and understanding. To date, the United States need not fear the judgment of history regarding the success of our mixed system in terms of both research and graduate education in the physical sciences. Our system has proven to be fully competitive on a world-wide basis.

I. SETTING OF PRIORITIES

The determination of priorities in science is a dynamic, complex, and subtle matter requiring a balance among many different considerations ranging from the quality of the people in a field to the estimated value of potential applications. It is sometimes asserted that the scientific community has no system for determining priorities within science, and that the Federal Government has no policy for allocating scientific resources. Neither of these statements is true.

The fact that much of science does not use a highly visible, centralized, priority-setting mechanism does not mean that other mechanisms do not exist. Actually, science uses a multiplicity of such mechanisms. One priority-setting mechanism operates when a scientist determines the problem on which he works and how he attacks it within the resources available. This determination is made taking into account other similar and related work throughout the world. Another mechanism operates as proposals of competing groups of scientists are evaluated and funded on the basis of systematic refereeing and advice of peer groups. Still another mechanism operates as aggregate budgets for various fields of science are influenced by the number and quality of research proposals received in that field. Like any market mechanism this system is not perfect and requires regulation and inputs from outside the system itself. Such inputs come from the mission-oriented agencies which balance their needs for new knowledge against their operating needs and from a whole host of outside judgments implicit in the budgetary and appropriation process. Trouble occurs either when these external judgments are completely substituted for the priority setting of the scientific community or when the priority setting of the scientific community becomes too autonomous.

The decentralized scientific priority-setting mechanisms are aimed at making growth of scientific understanding and insight as rapid as possible, but scientists do not live in a vacuum and are sensitive to the concerns and priorities of the society around them, as well as to the problems of mission-oriented agencies which have research funds. Academic scientists are especially sensitive to the interests and concerns of students who come into the scientific enterprise with new ideals and values not completely determined by the perspectives acquired by the senior scientists in the course of their working lives. The continuing entry of able and energetic students into the scientific process tends to stimulate a continual reevaluation of priorities among academic scientists and within the scientific community as a whole. The process of selection of faculty members for universities is itself another decentralized priority-setting mechanism; the interests of faculty determine the choice of research problems and the type of proposals which are submitted. Faculty members are not paid primarily from Federal funds. Therefore, the faculty selection process is in large measure an independent input to the priority-setting system.

The somewhat idealized system described applies primarily to research activities which involve relatively small grants with individual investigators working with a small group of students and colleagues. These natural priority-setting mechanisms in fields dominated by such activity work quite well, and little is to be gained and much may be lost by trying to establish and enforce a highly centralized priority determination. An area of concern might be the possible neglect of certain underdeveloped subdisciplines because they may have too few scientists to attract the attention they deserve, and existing proposals may be underrated even by peer groups. Such subdisciplines may include fields which are of importance for applications but do not appear to be as scientifically challenging as other areas, often because the general problems are not subject to easy dissection into manageable research problems. Current examples of possibly neglected subdisciplines may be electrochemistry and analytical chemistry.

Special measures to stimulate proposals in such fields may be desirable. One well-tried method, for example, is the use of a sheltered competition among research proposals in a well-defined area. To some extent basic research supported by a mission-oriented agency always constitutes such a sheltered competition, bounded by the mission relevance of the subject matter. However, there are also the dangers that a sheltered competition will attract proposals of low scientific quality and will prolong some projects beyond the point of usefulness. Once a sheltered competition has developed a sufficient number of proposals of high quality to compete on their own terms in a broader field, the purpose of the program has been realized. It should then be phased out gradually, but with an accompanying increase in aggregate funds to take into account the newly established research programs.

The problem of priorities is rather different when major facilities or the creation of new research institutions is involved. Here some form of central determination is essential because such expensive facilities cannot be duplicated extensively. Later we indicate some of the factors that ought to be considered in allocating funds for major new facilities in the physical sciences. Once the commitment has been made to construct and operate major facilities, national planning must assure the funds necessary to utilize the facilities effectively, including adequate funding for the programs of user groups. For each facility there exists a range of productive operating levels. Below the low end of this range it becomes difficult or impossible to keep first-class scientists involved and interested, and the operation becomes ineffective. There is another higher level of operation and utilization above which the use of the facility may result in diminishing returns when compared to alternative investments. When agencies plan for the allocation of operating funds, including the support of outside user groups, they must plan so that the level of utilization lies between the extremes mentioned above and so that the program is in reasonable balance with related work. Since the United States accounts for about thirty percent of the world output of papers in the physical sciences, it is reasonable to expect that it should account for this proportion of the truly important contributions in those fields of science requiring major facilities and instrumentation.

At any time there will be certain fields of science that are particularly ripe for exploitation and which deserve special priority in terms of facilities investments. We believe that examples of such fields within the physical sciences are radio astronomy and the even newer observational astronomy windows (gamma rays, X-rays, infrared, energetic particles, and the solar wind) which the earth's atmosphere partially or totally obscured prior to the development of our competence with balloons, rockets, and satellites. On the other hand, we feel it important to note that the term "priority" not be interpreted so as to result in complete stagnation in all other fields of the physical sciences or in excessive concentration on programs requiring major one-of-a-kind instrumentation. Also, in making facilities investments we must realistically appraise the prospects of success. Investments merely for the purpose of "catching up" with other nations are likely to be wasteful unless they place us truly at the forefront. We run the risk of this happening if we delay too long in implementing plans which have reached a certain stage of maturity. In such cases it may be more economical in the long run to make an even larger initial investment in order to "leap-frog" capabilities existing elsewhere than to make a more modest investment to duplicate or parallel capabilities already existing.

Dynamic, complex, and subtle systems for setting priorities are common in everyday life. A fire in the home or a sick child may instantly change a man's priorities. Such effects also exist in our political sector. An agency's annual budget summarizes and states the agency's priorities for that particular year under the known constraints. Many problems and alternatives have been considered in the course of preparing that budget, and it contains, either explicitly or implicitly, a complete statement of established priority.

III

Health of the United States Effort in the Physical Sciences

Science has always flourished in those nations which were the economic and industrial leaders of the world at the time. Contrary to a common belief, the excellence of the United States in the physical sciences was already beginning to be evident early in the twentieth century. A continually rising investment in research in the physical sciences and a steady growth in the number of scientists, even during the depression of the 1930's, coincided with a rapid evolution of scientific achievement and technological capability in the United States. This state of affairs is no coincidence, for the science and the economy of a nation are mutually interdependent. Advanced industry provides the capability for research, and research creates the knowledge out of which the advances in technology are conceived or developed.

The progress of science is also one measure of the advancement of a civilization. Man's understanding of the universe and his ability to describe, predict, and control his environment are measures of his culture, and the degree to which a nation contributes to this common human enterprise is a measure of its place in world civilization. A nation which turns inward on itself and becomes exclusively preoccupied with its own immediate problems will not only lose its claim to respect in the world but may fail to solve those problems as well. The determination of the size of the national support of science is an important decision for the Nation. The multiple relationships between science and the rest of society make that decision particularly difficult because adverse effects will appear only slowly and will become increasingly difficult to reverse as the state of United States science subtly deteriorates. The public and its representatives and agents in government must be aware of the importance of progress in fundamental science to the solution of the problems currently facing the country and to the anticipation and solution of the problems which will surely face it in the future as populations grow and as the world society increases in complexity. The interdependence among the sciences means that we cannot progress very far either in societal problem-solving or in scientific understanding if we attempt to work too selectively on those parts of science which are perceived at any given time as self-evidently relevant to the current problems and concerns of the society. The advancing fronts of knowledge, understanding, and application are too closely interconnected for such an approach. A narrow approach would be nowhere more damaging than in the physical sciences, which provide the conceptual framework and the tools of measurement for much of the rest of both science and technology.

The world scientific enterprise is a mixture of cooperation and rivalry—among individuals, institutions, and nations. Both the competition and the cooperation are necessary. A strong national scientific enterprise is necessary to appreciate, utilize, and exploit the discoveries of others. Because of the breadth of its scientific effort, the United States has been in a position to take advantage of many ideas initially conceived elsewhere in the world. Now United States leadership in science and technology is being challenged not only by the Soviet Union but also by Western Europe and Japan. In Western Europe and Japan investments in basic physical science and related education are growing at rates comparable to those in the United States during the late 1950's and early 1960's, and that growth is occurring in the newest, most promising or exciting fields. These nations are in a good position to take advantage of the latest capabilities in instrumentation and experimental techniques because they have small commitments to older equipment and facilities. To remain at the forefront the United States must maintain a distributed, but balanced, effort—incorporating the very new but at the same time retaining much that is familiar. This need is not unique to science. A football team composed entirely of seniors may have an all-winning season, but graduation leaves the Old School destitute of experienced players the following season. A team comprised entirely of sophomores may sometimes be necessary and may seem to have certain advantages of youth in the early quarters. However, they may fail under the pressure of the final few minutes and lose to a more experienced team. The ideal team then is a mixture of veterans and rookies. It is the coach's job to field the right mixture.

The fruits of international science do not appear solely in the economy but appear also in our general culture. The influences may be either subtle or dramatic. The thrill of human accomplishment when a man first stepped on the moon was not nationalistic but was shared by most of the peoples of the world. In a much less obvious way the recognition of common motives in science has a unifying effect similar to that found in world literature and world art. The scientists of this country will continue to make their contribution to our position of international leadership if our present momentum in science is maintained.

About five years have elapsed since publication of the reports of the National Academy of Sciences on ground-based astronomy,[1] chemistry,[2] and physics.[3] Each of these reports attempted to project ahead five years rather carefully and ten years in a more speculative fashion. Reviewing the five-year projections, one cannot fail to be struck by the enormous vitality and productivity of the physical sciences during this period. In almost every case, the scientific accomplishments since 1964-65 have considerably outrun the expectations at that time. There have been general gains both in fundamental insights from specific discoveries and in the development and exploitation of new observational and theoretical techniques.

The present vitality of the physical sciences, despite budgets which fall well short of the funding recommendations in those National Academy of Sciences reports, is being sustained largely by the results of past scientific investments, both in manpower and in equipment, and by the continuing hope of the scientific community that the lag in public support is temporary. Scientists still are generating new instrumentation ideas and new research plans because most of them believe that some of these plans will come to fruition in the near future. Should confidence in this belief fade, the adverse effect on productivity in the physical sciences would be serious.

The physical sciences effort in the United States is a joint venture of universities, Government, and industry. Each of these partners provides personnel, funds, and facilities. Yet each partner has a different reason for doing science and, therefore, performs a different and necessary function in the whole system. We believe that this partnership enables the United States to use its resources extremely productively. For example, during 1967 the Soviets launched 67 scientific spacecraft compared to 31 launched by the

United States. Yet almost all the advances in space and planetary science came from the United States program. This is due in large measure to the more general involvement of the scientific community in these experiments, to the cross-fertilization of ideas resulting from the greater breadth of the United States scientific effort, and to the excellence of the output of United States industry.

Today our Government, our universities, and our industries jointly hold the greatest research capability in the physical sciences that the world has ever known. They do so, moreover, at a time when the physical sciences face the most exciting prospects in history for discovery, for understanding, and for applications to many diverse needs of our society. It is sadly inconsistent that inadequate funding frustrates their ability to respond to new ideas and new opportunities and threatens the United States scientific effort with mediocrity.

Before turning to details we conclude this general assessment by reemphasizing that the outstanding progress in the physical sciences during recent years, both in fundamental discoveries and technological applications, has been achieved with nearly level research budgets and with major facilities which are rapidly becoming obsolete. It is clear there will be a day of reckoning for United States science and for the national well-being. That day may be very near—the highest energy accelerator is in the Soviet Union, not the United States; clashing-beam apparatus exists in Western Europe, not the United States; a nuclear accelerator specifically devoted to studies of astrophysical reactions exists in France, not the United States; new radio telescopes are being built elsewhere, not the United States; pulsars were discovered in Great Britain, not the United States; major United States manufacturers of modern chemical research instrumentation now find that approximately fifty percent of their market lies abroad.

A. THE UNIVERSITIES

1. UNDERFUNDING OR OVEREXTENSION?

Universities have always been beset with problems. In spite of this fact, during this century United States universities have built an impressive record of achievement and of excellence in teaching, in research, and in public service. Furthermore, they have always been sensitive to the need to extend higher education to an increasing fraction of our population. They now find themselves caught in a dilemma; changes in style, many of them costly, are obviously needed at a time when current financial problems seem enormous. The higher education system in the United States is seriously overextended in terms of the availability of funds to meet its responsibilities. The universities and colleges expanded in response to the urging and inducements of society and of government at all levels. However, even the short-term adjustments to immediate social and educational needs require these institutions to make long-term commitments. This is true in almost every aspect of their operation. It is especially true for programs of research and training in the physical sciences. For the past decade, the universities expanded the base of graduate-science training and research in response to national needs and implicit national policy. The product is an immensely valuable national resource of faculty and students, buildings and capital equipment. By urging the need for more scientists with advanced training and by making many of its own commitments contingent on matching long-range institutional commitments, the Federal Government has assumed a share of the responsibility for academic science which goes far beyond particular research projects. It must meet this responsibility by sustaining the enterprise which it helped to create. Otherwise we may end up with a large assembly of excellent institutions and talented research groups which do not have sufficient support to remain vital and productive.

The tremendous expansion in graduate education and research has been heaviest in fields such as chemistry, solid-state science, and atomic and molecular physics. Many developing institutions have turned to these fields because, in addition to offering many exciting scientific opportunities, they are cheaper on a per scientist or per student basis. These are good areas in which to start a development effort, but existing funds have been spread so thinly that it has become increasingly difficult for even a burgeoning institution to find support.

For example, the number of Ph.D.-granting chemistry departments in the United States grew from 110 in 1957 to 172 in 1967; that number has now passed 200. The increase in chemistry staff at Ph.D.-granting institutions is projected to grow at a rate of ten percent a year for the next ten years. This growth will be heavily concentrated in the newer or smaller departments which, therefore, will have to be equipped almost from the ground up at an average cost per department in excess of one million dollars. The limited funds for chemistry instrumentation in the budget of the National Science Foundation have precluded a truly balanced program. At the same time there is ample evidence that such instrumentation is essential to most of the important new discoveries in chemistry.

In Europe, the Soviet Union, and Japan one can identify in many fields of science a laboratory or research group which is better funded, better equipped, and better staffed than any single laboratory in the United States. This is true despite the fact that total United States support in the field exceeds in most cases that of other nations. In other words, the lag in financial support in the United States is creating a situation in which our scientific effort is too widely dispersed for the resources available. We emphasize that this is a recent phenomenon, born partly by the impressive effort on the part of other nations to catch up with the United States and partly by the lag in the last three or four years in the support of basic science by our Government. Even in those few years, however, the gap between what could be done productively and what can be done practically within existing budgets has become so large that we must examine the basic policies and tenets of our present support system.

In this situation we are faced with three choices of policy. The first would be to continue as at present with level or declining funding but attempt to maintain the present broad base of graduate departments and national laboratories. This course of action would continue to spread resources thinner and thinner. The second choice would be to accept present funding levels indefinitely and begin a planned phasing out of a number of laboratories and graduate science departments. This course of action would free funds to build up a concentration of equipment and people in fewer places, judged to be most likely to push the cutting edge of the United States scientific effort. The third choice would be to implement what appears to be a continuing national commitment to excellence in science as well as to a broad and broadening base of opportunity for participation in graduate training and science and

to provide the resources necessary. We have considered these alternatives carefully, but the following discussion shows that the third alternative is the only one which is realistically open to the Nation.

Our population with ages between 25 and 45 years is projected to reach 62.4 million people in 1980, barely ten years from now. That is the group which will be doing most of the Nation's work and rearing most of the Nation's children.

Figure 1 permits a comparison of the slopes of three separate graphs:

I. Gross National Product in Billions of (1958) Dollars.[4]

II. Population in Millions of People with Ages between 25 and 45 Years.[5]

III. Federal Obligations to Universities and Colleges for Research and Development in Millions of (1958) Dollars.[6]

Graph I and Graph III have each been corrected to 1958 dollars by the same implicit price deflator.[7]

Figure 2 is a superposition made by arbitrarily setting the value in 1967 of each of the three graphs separately equal to 100. This is done solely to facilitate discussion of the three graphs and involves no assumption concerning the adequacy of 1967 level of support. Although we do not believe that the Federal support of research and development in academic institutions in 1967 was an optimal figure, we do believe that in general the projection of Graph III should fall between the projection of Graph I and the projection of Graph II. The Nation cannot afford to sustain a projection of Graph III in excess of that of Graph I over a period of many decades. However, an opportunity for a major effort towards the solution of a national problem, such as air or water pollution or the discovery that we are dangerously behind the world competition, as in the case of Sputnik, would certainly justify for a limited period an increase in the support of science at a rate greater than the projection for Graph I. However, only the most extreme of national disasters should be permitted to drive the projection of Graph III below that of Graph II. In that case we would begin to lose the most vital component of the overall scientific enterprise—newly trained young people. We will not be able to

Figure 1

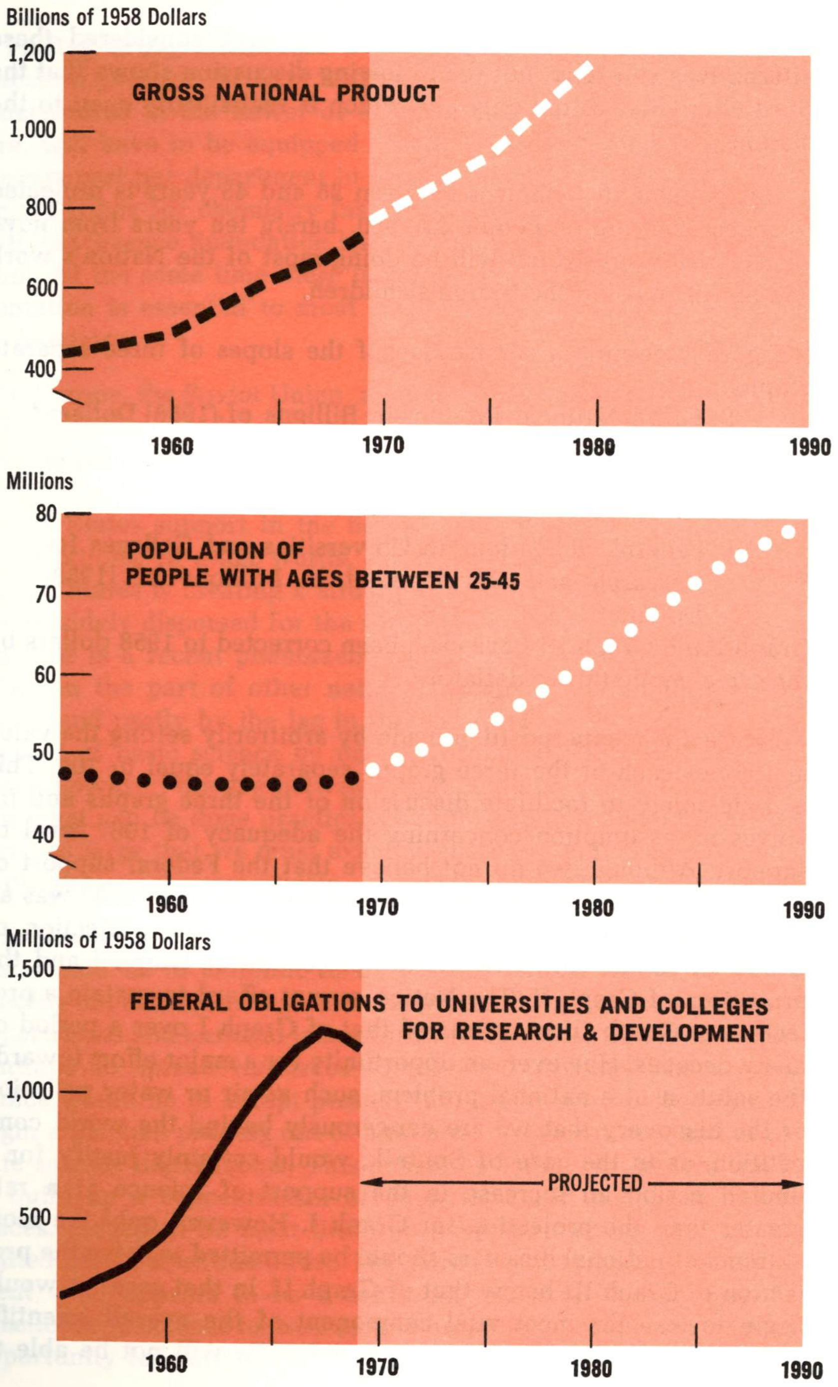
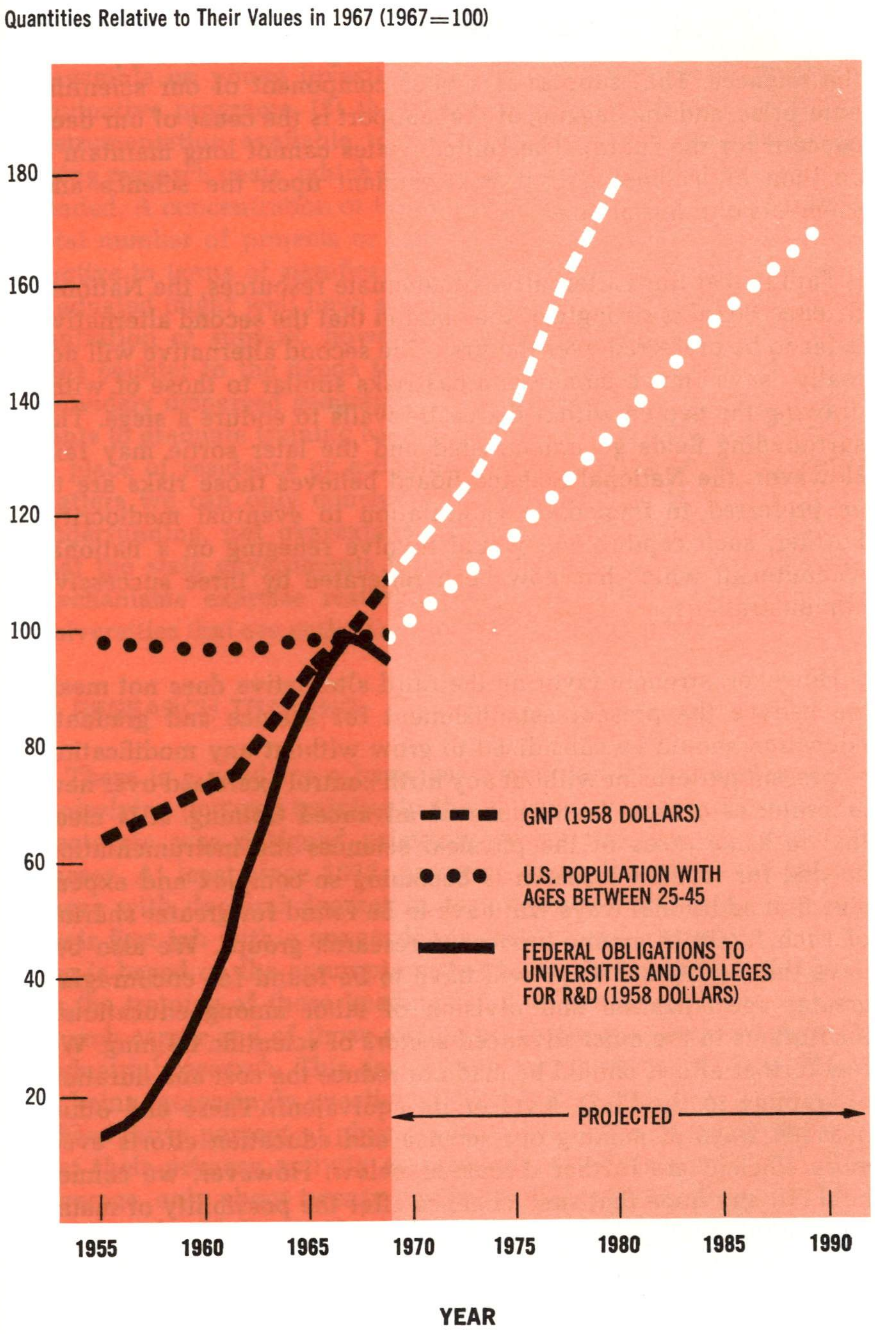


Figure 2 **A COMPARISON OF GROWTH**



supply the rapidly growing group of adults with the jobs, goods, and services which it both deserves and expects, if the Federal Government does not restore reasonable growth to its support of the sciences. That support is a vital component of our scientific enterprise, and the flagging of that support is the cause of our deep concern for the future. The United States cannot long maintain a position of leadership if it is dependent upon the science and scientists of other nations.

Failing that third alternative of adequate resources, the National Science Board is strongly of the opinion that the second alternative is far to be preferred over the first. The second alternative will not really "save" much money and has risks similar to those of withdrawing the people within the castle walls to endure a siege. The surrounding fields go unharvested and the later sortie may fail. However, the National Science Board believes those risks are to be preferred to immediate capitulation to eventual mediocrity. Further, such capitulation would involve reneging on a national commitment which has now been reiterated by three successive administrations.

However, strongly favoring the third alternative does not mean we believe the present establishment for science and graduate education should be subsidized to grow without any modification of present patterns or without any birth control exercised over new laboratories or new institutions of advanced training. It is clear that in some areas of the physical sciences the instrumentation needed for frontier research is becoming so complex and expensive that additional ways will have to be found for greater sharing of such facilities among numerous research groups. We also believe that additional ways will have to be found for encouraging greater specialization and division of labor among educational institutions in the most advanced sectors of scientific training. We feel further efforts should be made to reduce the cost and duration of training to the Ph.D. level or its equivalent. These and other possible ways of making our science and education efforts even more efficient are further discussed below. However, we cannot hold out any hope that such changes offer the possibility of maintaining the productivity of our scientific enterprise on a level budget, and we urge in the strongest terms that any attempt to do so would be a costly deception of the Nation.

This country's research productivity in the physical sciences will certainly be condemned to mediocrity if a number of factors continue to converge as they have in recent years: (1) the inability to gamble on young investigators without emasculating existing productive programs, (2) the inability to make modern research instrumentation available to Ph.D.-granting institutions, and (3) rising research costs, which leave almost every single effort underfunded. A concentration of the available money spent on a smaller total number of projects or institutions might well be more productive in terms of significant scientific results, and the scientists graduated might well have a better research training. Such a concentration of support, however, is not recommended because it runs counter to the needs for first-class training opportunities to be widely dispersed geographically and equality of access by students to graduate training based on ability alone without reference to place of residence or economic status. Having reviewed these matters we can only conclude that the problem is truly one of underfunding, not overextension. We do recommend, however, that the state governments through their individual coordinating mechanisms exercise restraint on the number of colleges and universities that are authorized to offer the Ph.D. degree.[8]

2. RESEARCH TRAINING

There is a need for a basic reexamination of the assumptions underlying doctoral training in the physical sciences. The present doctorate was designed primarily as training for an academic career. At least since 1935, however, more than fifty percent of those with doctoral degrees in the physical sciences have taken their first job with a nonacademic institution.[9] The present training is based on the assumption that there should be no difference in the training of those heading for a university teaching and research career and of those aiming primarily at college teaching or industrial research. This assumption may well be justified, but it is being increasingly questioned. Ten years beyond the Ph.D. only about thirty percent of physical scientists in the National Register list their primary activity as research and development. On the average, only about twenty percent of the physical scientists who receive the Ph.D. continue to contribute to the basic scientific literature over the long term. Such facts indicate that this problem needs serious investigation with the aid of detailed empirical studies of the career experiences of persons who hold a doctoral degree in the physical sciences.

The problem may not be so much one of the content of the educational experience as it is of the attitudes and values communicated by the organization and orientation of the graduate school. Experience in basic research on significant scientific problems is excellent preparation for more applied work and for technically oriented management and administration. The laboratory techniques of basic research today often become the techniques of applied research and engineering a few years hence. The critical attitudes and intellectual standards characteristic of the best research have an important carry-over into more applied or problem-solving activities, and basic research is probably an ideal vehicle for learning such approaches. On the other hand, the transfer of these attitudes and approaches to other areas of technical activity may not be automatic and might be more emphasized in instruction. Basic research training also carries the hazard of overemphasis on a narrow problem area or on a set of specialized techniques.

There is increasing belief that a somewhat different type of training, equivalent in intellectual stature to the present Ph.D. but aimed more suitably for nonresearch careers, should be available. Such training would still involve basic research experience, but possibly with greater breadth and variety and less depth and specialization than the present degree. In the light of evolving industrial needs and changing social priorities, a more nearly fixed time period, less sharp specialization, and less emphasis on an original, discrete contribution to knowledge should all be considered as possibilities in any review of the doctoral program. Consideration should be given to providing the student with a wider diversity of opportunities as he pursues his education. One possibility would be the establishment of practitioners degrees at the doctoral level. Deep specialization and an original research contribution might well be reserved for postdoctoral experience for students showing talent for making such contributions to science.

Further, wherever interdisciplinary education exists at the graduate level in universities, it provides a route for rapid transfer of new science into engineering or applied effort. Such programs are often especially useful in improving or expediting communications between industry or Government and the academic world. Good multidisciplinary programs, however, are still less common than is desirable. Some reluctance to initiate work spanning the traditional branches of the physical and life sciences, engineering, and the social sciences is clearly based on conservatism, but there are also very legitimate concerns. There is the danger that wide focus may generate superficiality because there are fewer external standards against which to judge quality and success. The costs of initiation may be much higher than those for beginning new work in an established field. The potential rewards in terms of increased exchange of ideas and concepts are so great, however, that special efforts should be made to stimulate and support good multidisciplinary programs. This would provide many opportunities for industry, with its already more effective interdisciplinary structure, to nurture a similar mood in the graduate teaching of physical science.

3. SOCIAL IMPLICATIONS

There is an increasing interest in the social and political implications of advances in technology and concern with the ways in which science is utilized by society. We welcome this increased interest and concern as an opportunity for physical scientists in particular to establish greater intellectual connection with the rest of society, with the rest of the university, and especially with the younger generation.

Many students feel increasingly threatened and alienated by technology and often confuse science with technology. To an unhealthy degree today's undergraduate regards study beyond the elementary level of the physical sciences as suitable only for the future specialist. Substantial effort and thought on the part of physical scientists both inside and outside universities will be required to reverse this situation, but this effort appears to be important in order to improve the ability of our social institutions to deal with the increasingly complex effects of technology. The current interest in the implications of technology may help provide more effective communication within the academic community. In addition, the problem of assessing the potential effects of technology and evaluating the increasing range of alternative technologies available to society can provide an important new motivation for both basic and applied research in the physical sciences.

4. CLASSIFIED RESEARCH

Classified research in the physical sciences was originally undertaken in universities as an emergency measure because that was where the necessary competence existed. Recently there has been a trend towards phasing out such activities, and the Department of Defense is to be applauded for reexamining its classification policies for university research and in many cases for declassifying the work. In the long run, classified research is incompatible with the principle of an open scientific community and with the concept of science as public knowledge, open to criticism and verification by the entire scientific community. Just as there is a perennial problem with industrial security, so may governmental classification impede efficient communication. Such classification, which may provide a measure of security in the short run, may also retard progress and thus reduce security as well as the social benefits of science in the long run. Thus secrecy in physical science research can seldom be justified as in the long-term national interest and is especially incompatible with the character of the academic community and the requirements for the training of students. Mission-oriented agencies should be encouraged to reexamine continually their classification and publication policies with a view to increasing their openness to free dissemination and criticism. This applies with particular force to academic science but is in the national interest even with respect to scientific activities of other types of institutions. The National Science Board recognizes that complete openness is not possible in every single instance, but it believes that the burden of argument should always lie with those who advocate restriction of the flow of scientific information and that the process of security classification of research should itself be subject to the scrutiny of disinterested parties.

B. THE GOVERNMENT

In 1939, President Franklin D. Roosevelt was explicitly informed of the German discovery of nuclear fission and of its implication

that a large-scale release of atomic energy might be practicable. Physicists of that time found it necessary to call upon such a legendary figure as Einstein to urge action by the President because the significance of this discovery was not immediately apparent to other levels of the Federal Government. Furthermore, the Government had no avenue for exploiting it. It was fortunate that our Nazi adversaries had none either. Nor did they have the means of getting the attention of their leader in order to create the vast enterprise required for making nuclear weapons. We may be thankful that the situation was not reversed. Today, involvement of the Federal Government in the physical sciences precludes such a major disaster because there is little chance that even a minor advance in fundamental knowledge will escape attention. Failure to carry an advance into application is usually the result of a considered political or administrative decision that it is undesirable because of cost or other reason. The participation of many agencies of Government in the basic physical science research enterprise of the whole Nation has the vital effect of keeping these agencies aware of the forefront of technology and of assuring them of the opportunity for acquisition and assimilation of new basic knowledge as fast as it is developed.

1. BASIC RESEARCH

The tremendously important historical role played by various components of the Department of Defense in pioneering support of basic research in the physical sciences and in the application of new techniques to basic science must not be overlooked. In the years since World War II the Department of Defense has interpreted mission relevance in a liberal and enlightened way. This permitted and encouraged the development and application of new techniques developed under defense auspices within a wide scientific context. There are many areas in which defense support has played a key role. It was the Office of Naval Research that supported the development of the commercial helium liquefier that made low-temperature techniques widely accessible. It largely pioneered the field of radio astronomy and, more recently, the use of cyrogenic techniques for particle accelerators. Through the Advanced Research Projects Agency, the Department of Defense has supported development of the most sophisticated computer software. It has also been partly responsible for the dramatic revival of atomic and molecular physics. In general, the Department of Defense has shown an ability to move quickly to exploit new scientific opportunities and to move with sufficient resources to make a large impact in a short time, as it did with lasers and nonlinear optics. The Department of Defense also pioneered the project support system which permits individual scientists throughout the country to compete on a national basis for the available funds on the merits of their proposals. There is no doubt that national competition has made a tremendous contribution to the high average quality of work supported by Federal funds. In the current public disenchantment with many defense-supported activities, it would be tragic if the unusual and innovative role of the Department of Defense in the basic physical sciences was lost.

Each Federal agency which supports basic research has made similar contributions to the total scientific enterprise. The Atomic Energy Commission created national laboratories which, in addition to pursuing their own research missions, are models of effective service to the university community. The National Institutes of Health has an unusual and successful mixture of intramural and extramural programs. These health-related programs have rightfully included a great deal of modern chemistry. The National Aeronautics and Space Administration has provided a space capability for future exploitation. However, even these characteristics cannot insure success of the overall national effort. Increasingly the Department of Defense and other mission-oriented agencies have felt unable to provide the more stable, long-run support which is so essential. The National Science Foundation has the responsibility to insure such stable support. However, at present it is inadequately funded for the job.

2. MISSION-ORIENTED RESEARCH

In the physical sciences, mission-oriented support has been an important source of intellectual stimulation and should be continued. Mission-oriented work often presents new scientific opportunities which would not have been recognized without the stimulation of the mission even though later evolution of the work might take it well beyond the scope of the original mission-oriented problem. Radar and radio astronomy, for example, would probably never have been undertaken for their own sake if large radar antennas had not been built originally for applied purposes. Development of pure materials for technological application has enormously stimulated fundamental investigation in solid-state science by providing reproducible materials for study. Technological support for the development of superconducting magnets came largely from the Atomic Energy Commission and was justified primarily by the needs of research programs directed toward controlled thermonuclear reactions, and secondarily by the need for cloud chamber magnets. The Atomic Energy Commission development, support, and demand for such magnets resulted in a commercial availability which has brought enormous benefits to general, solid-state science. The specialized interests or perspective of mission-oriented agencies provides stimuli for new instrumentation and new experimental techniques which purely scientific motivation might not generate. Computers provide a generalized example of this. The scale of support for computers for defense and space purposes has resulted in benefits to all branches of science which would not have been available if computers had been developed only for their scientific value. Mission-oriented support in universities helps assure that new techniques flow into the general scientific enterprise.

Mission-oriented support of basic research in the physical sciences has also helped set high scientific standards for the applied efforts. The success of United States science in comparison to that of other countries owes a great deal to the close involvement of academic science with mission-oriented support, and the success of United States technology owes much to its close association with basic science. While this is especially true in the physical sciences, newer, social-problem-oriented agencies may also benefit from a similar pattern.

3. RESEARCH FACILITIES

Large installations at many Federal laboratories are somewhat overequipped in comparison with the staff available to use the facilities, largely as a result of manpower ceilings on those laboratories. Conversely, there is now a serious deficiency of funding in academic institutions in relation to the number of scientists qualified to do good research with the equipment currently available.

Consequently, a disproportionate fraction of our total resources is going into sustaining programs and facilities in existing laboratories and not enough into new starts. This situation is quite serious in the research programs concerned with the physics of nuclear structure and of elementary particles where the present plant is seriously underutilized and threatens to become more so as major new facilities come on line. Accelerators have grown in size, complexity, and cost from the relatively primitive cyclotrons built in the 1940's and the 1950's to such major national facilities as the Stanford Linear Accelerator. Agencies supporting programs in nuclear-structure physics and in elementary-particle physics do not have the funds to exploit all the existing facilities to the full extent of their capability and at the same time to provide for the new ones under construction or in the conceptual-design stages.

If we are to have a balanced program, however, there is no choice but to move ahead with the design, construction, and operation of accelerators with new capabilities, as well as modern ancillary facilities, such as bubble chambers, optical spark chambers, filmless spark chambers, on-line computers, and other tools used for the detection and observation of particle interactions. Such construction must proceed even if it means curtailed programs at existing machines, though in the long run such practice may turn out to be a false economy.

The new 200 Bev accelerator near Chicago is well underway. Another major advanced accelerator is under construction at Los Alamos, New Mexico. At such accelerators about eighty to eighty-five percent of the annual cost would be necessary to keep the operation going without doing any research. Thus, the remaining fifteen to twenty percent of the support is the margin to cover experimentation and innovation. Furthermore, the costs escalate at about eight percent per year. Consequently, on a level budget the margin for science will rapidly shrink to the vanishing point unless some installations are phased out altogether in order to release funds to support the remaining laboratories and the new laboratories that will soon come on line. We have already discussed the probable futility of a policy of undue shrinkage.

In both radio and optical astronomy the situation is somewhat different. Here there is a deficiency of equipment of frontier observing capability but still well within the current state of the art of design and construction. In the last three years Federal support for astronomy instrumentation has been dictated almost exclusively by economic considerations and has not reflected scientific needs and opportunities. There is also a much larger demand for observing time than can be met by existing facilities at full utilization. Here a shortage of funds for investment in modern sensing and data-processing equipment has prevented astronomers and astrophysicists from getting the most out of the existing facilities.

There is always the problem of striking a balance between large frontier research facilities and smaller research projects. This problem is acute in many areas—radio astronomy, optical astronomy, nuclear-structure physics, space science, and an increasing number of subareas of chemistry and solid-state science which require special instrumentation, such as low-energy particle accelerators, high magnetic fields, high-pressure equipment, or very low temperatures. There is need for greater specialization in instrumentation and greater division of labor among institutions and research groups. Regional facilities may become increasingly important, but such facilities require resident staff to keep the program vital, to continue to develop new techniques, and to help visiting scientists with the latest instrumentation. The present pattern of users groups in high-energy physics is likely to spread increasingly to other areas of the physical sciences in spite of great organizational difficulties. The trend towards on-line instrumentation and control of experimental variables by computers, which is now so pronounced in nuclear-structure physics, is also appearing in other parts of physics and chemistry. Such a trend must be made compatible with the pattern of decentralized research which has proved so stimulating to United States productivity. In a period of increasing centralization of front-rank facilities and research techniques, we must preserve a healthy measure of institutional and individual competition while avoiding a self-defeating scramble for resources. Doing so will not be easy and will not be cheap, but it has been demonstrated that this can be done; we must proceed to do it on a larger scale.

The balance between necessary regionalization and centralization on the one hand and the many necessary autonomous research groups on the other is very difficult to establish in practice.

Smaller facilities, readily accessible to local faculty and students, are very important in the design of experiments and in optimizing them before making use of major facilities. The high cost of experimentation with frontier research facilities makes careful preliminary design and testing mandatory. Thus, the decision between national facilities and local research support is not a case of one or the other. An extreme in either direction makes for a less productive scientific enterprise. Local facilities, moreover, usually have a much quicker response time in following up new opportunities and new discoveries made with major facilities. There is a constructive interaction between local and national experimental capability; between centralized and decentralized facilities.

It is essential that frontier instrumentation be made available for the most significant experiments. Resident staff at installations with unique facilities must compete with qualified outsiders for instrument time. A system of peer judgments for this purpose has been well institutionalized in the case of higher-energy physics. It may become increasingly necessary in other fields as well.

An especially acute problem may arise in the case of facilities funded by a mission-oriented agency for a rather specific purpose but which have more general scientific value. Examples are the Arecibo antenna built for ionospheric scattering work; the Goldstone space-tracking antenna of the Jet Propulsion Laboratory, National Aeronautics and Space Administration; and the Haystack radar of the Lincoln Laboratory. The subject of radar planetary physics has developed largely as a by-product of military radar development. Other examples are the reactor at the National Bureau of Standards, the satellites of the National Aeronautics and Space Administration, and the rocket astronomy capability at the White Sands Proving Ground. Declining priority for a particular applied mission should not justify closing down a unique facility if its potential productivity in a scientific context beyond the mission of the supporting agency justifies maintaining it. This consideration, of course, extends to modifications and capital improvements of such instrumentation. Again Arecibo and Haystack provide good examples. A similar issue arises in connection with nuclear chemistry and solid-state work on accelerators which may have become outmoded for nuclear physics. There are problems both of changing priorities as scientific opportunities unfold and of handling the associated funding problems among agencies.

We heartily endorse the recently announced Government policy of making the facilities of Federal laboratories available as far as possible to the academic community even when the work does not meet the strictest test of mission relevance. The implementation of this policy will require careful coordination at the Federal level. Unilateral action by mission-oriented agencies without due regard to the effect on the development of science can be very wasteful. The alternative to such waste is more coordinated planning for basic science on an interagency basis together with flexibility for reprogramming of the budgetary responsibility among agencies that must go with such coordinated effort.

The National Science Board has studied résumés of needs for new major facilities for the physical sciences. No group can state a detailed set of absolute priorities over such a broad spectrum as presented by the physical sciences. We can, however, state certain principles which we think should govern detailed selection in any field of science.

1. New proposals for one-of-a-kind facilities which are within the state of the art and offer significant advances in the range of parameters which can be studied should generally be given preference over duplication of existing facilities for additional research groups.

2. The scientific importance and novelty of a proposal should be given greater weight in the choice of major facilities than any alleged applications because experience seems to demonstrate that in the long run this also leads to the greatest impact on technology.

3. Although the capability to attack identified scientific problems should be a major consideration in choosing facilities, it should also be recognized that any extension of measurement capabilities into new domains of physical conditions is likely to yield unanticipated discoveries. Thus, extension of capability by itself should be given considerable weight even when the problems to be attacked cannot yet be clearly formulated.

4. As a rule, at comparable cost levels, general-purpose or multipurpose facilities should be given priority over special-purpose facilities with a limited domain of scientific useful-

ness. Total probable impact on a group of sciences or applications should be given more weight than impact over a more limited span of problems, no matter how challenging.

5. Complementarity to facilities available in other countries should be given important weight. Maximum advantage should be taken of exchange of scientists and auxiliary equipment, such as sensors and computers. Advice of foreign scientists will frequently be useful before reaching final commitments; this will facilitate cooperation later.

6. The reputation and career commitment of the scientists backing a proposal for novel equipment or major experiments are important factors in choice.

7. Where there exists a number of proposals of a similar type, effort should be made to force a community consensus on the best approach within the resources available. As an illustration, there are a large number of proposals for heavy-ion accelerators and at least four proposals for high-intensity pulsed reactors under consideration at the present time. It is important that at least one of each type of these facilities be built in the near future, and it would be disastrous if the competing proposals were used as an excuse for inaction. However, an initial decision cannot await complete agreement on the best approach on the part of all those most concerned.

8. Operating costs should be factored realistically into budget projections when a project is initiated.

9. Mechanisms for the screening of experiments and projects proposed for major reseach facilities should be established to insure that each such facility is used in the most productive way possible. As far as possible, projects proposed by foreign scientists should compete on an equal basis with proposals of United States scientists.

4. UNITED STATES CAPABILITY IN SPACE

During 1969 the Apollo and Mariner successes dramatically demonstrated the magnificent capability of the United States space program. If we are to take advantage of this capability, it is imperative that a detailed future program be planned and that funds be made available for the development of the research programs and appropriate instrumentation. The trend to decrease funding for space science should be reversed. Space experiments generally must be planned at least five years in advance in order to allow for the development and production of suitable flight hardware and for complementary ground-based research. Provisions must be made for more active participation in these research programs by the academic scientific community. Adequate support for collateral ground-based, balloon, and rocket investigations is a current problem. The biggest problem, however, exists in the support of optical and radio astronomy, and the need for additional observational facilities in the Southern Hemisphere is especially crucial. Future decisions concerning high-energy particle accelerators may be guided by the results of cosmic-ray studies. The Soviet Union, through its proton satellite series, has already shown that significant elementary-particle physics experiments can be done in space. The United States now enjoys generally recognized leadership in space science. It should be realized, however, that this situation can change easily if we lose our best people from the space program.

C. INDUSTRY

1. THE NATURE OF INDUSTRIAL RESEARCH

The industrial research system differs from the research system in universities. The problems faced in an applied laboratory generally require an approach such as the following: (1) to define the problem so that the answers will bear as directly as possible on the application; (2) to do whatever experiments are needed to answer the question in the stated terms; and (3) to translate the answers into a process or product design. By way of contrast, the fundamental objective of most nonmission-oriented research should be the production of answers to problems in a form that allows the answers to be generalized as much as possible. In principle, the methods of such research are: (1) to conceive of the simplest experiment that will yield a useful answer; (2) to do the experiment with enough care and cunning so as to produce a substantially reliable answer; and (3) to extract all logically permissible conclusions and inferences from that answer. However, mission- and nonmission-oriented research interact, and productive interaction requires that each develop a distinctive style.

Research oriented toward generalization is most often found in the university laboratories; it is done by specialists and is often referred to as "pure" research, a completely inappropriate term implying an impossible value judgment. The generalized conclusions from research in university laboratories are continuously useful in applied research laboratories. Conversely, the existence of applied laboratories helps keep the specialists from having a sterile role in our society. Friction can arise because practitioners of each kind of research may conclude that the men in the other camp do not know the objectives of "real" research.

There is, however, considerable overlap in styles and purposes. Although generality is not the prime objective of most research in an industrial laboratory, important generalizable results may come from the work of any alert investigator. There are many examples of great science motivated by industrial pressures. One is Langmuir's work on tungsten, which is the base of the electric lamp industry. Electric lamps were being built but were expensive and had short lives. Langmuir, looking at that product, was motivated into a research program that concerned the economics of light bulb production, and his work also earned him a Nobel Prize. Another example is the transistor. The group that developed it saw needs in the electrical industry. The transistor revolutionized that industry, and the scientists who led the work in the industrial environment also received the Nobel Prize. If one studies such historical examples, one is impressed by how heavily the industrial work depended on related work going on in universities and Government laboratories.

Efficient communication among industry, Government, and universities requires a free flow of information. There is a tendency in industry to "overclassify" its work because of the perennial problem of industrial security. It appears more and more that the most dynamic industries, in a technical sense, are freer and freer with the flow of their research information. A careful distinction must be made between research information and engineering or technological information. Industrial firms, however, should consider whether they are overclassifying their research results and, thereby, inhibiting the flow of information and, in a sense, their own technical growth.

The most important interaction between industry and universities occurs because scientists who enter industrial laboratories are educated in universities, the principal location of general research. Casual critics often question the logic of training in one research system for a career in another. The orientation, however, of good university research toward generalizable conclusions provides students with a basis for flexible reaction to the necessary changes of objectives that must be characteristic of the program in a dynamic industrial laboratory. The belief that general solutions to physical problems exist and can be discovered by systematic study is inculcated, not as doctrine, but as experience, and what is learned is taken along to the new laboratory. This flow of recent graduates is probably the most effective tie between the two research systems.

Another profitable mechanism is the flow of senior staff among industry, Government, and universities: industrial people on leave for a limited period of time doing research at university laboratories, conducting seminars and courses; and university people in residence at industrial laboratories. This occurs on a limited basis. The major inhibitions against greater interchange of people are the concern in the industry to protect proprietary information and the attitudes in some universities. Both attitudes require modification, and increased exposure will help do that as well. Not all wisdom resides on the campus, and there are areas of science that are paced in industrial research laboratories. After industrial experience the faculty can profoundly influence the style and attitude of their students. Interchange between Government and both industry and universities would provide similar benefits.

An important sidelight of this problem arises because large industrial research laboratories usually are found only in large firms. The smaller firms would also benefit from such exchanges of people, but find them difficult to arrange because of their limited manpower. This whole area requires a thoughtful study to determine a mechanism that will accomplish the desired result.

The state of research in industry seems healthy, but it does face problems. Even companies which have been leaders in research now find themselves caught by the narrow margin that separates profit from loss even in the face of continuing expansion of the total volume of business. Those companies which reinvest four to five percent of their income in research do so with an acute awareness that the time lag cannot be long between most of their research and some reflection of it in their profit margin.

2. THE ROLE OF INDUSTRY

The role of industry in the research effort in the physical sciences is vital. Industry provides the mechanism by which the results of research are translated into goods and services for the use of society and also builds the instruments and facilities which are used to advance the sciences.

Industry's interest in research is motivated by profit. In large measure, profit is generated by the reduction of the fabrication cost and by the introduction of new products. In our society, moreover, cost reduction and new products are heavily dependent on technology. Contemporary technology, in turn, relies more and more on science and on scientific advances through research.

A firm must be aware of the structure of relevant scientific fields, the research activities in those fields, and the impact that the results will have on technology and on the profit of the firm. This knowledge provides a view of the technical options available to the firm and to its competitors. Providing this flow of information into the firm is one of the functions of research within a company.

Some sentiment has been expressed that all research which ultimately benefits industry should be done in industrial laboratories. Such a system, if it could be instituted, would be prodigiously expensive in our competitive economy. Most new scientific knowledge would become proprietary because no company could afford to release results until it felt it had exhausted the technological implications or until it was certain that competitors had the same information. The costs in duplication of effort and delay in dissemination of knowledge would be horrendous. For this reason many kinds of scientific research must be done in the public domain or not at all.

Since university research has great benefit to related industries, the latter have a vested interest in the health of university programs. This interest is often expressed in the form of direct financial support of university research and education, but such direct support provides only a small portion of the total need. Some companies are responding to the current crisis in financing university research by increasing their gifts. Unfortunately, there is no real prospect that direct industrial subsidy can provide any large part of the required funds. Fundamentally, the reason for this also lies in the nature of our competitive economy. To achieve a large increase in the direct subsidy of university research, some system would be needed to spread responsibility rather evenly among all members of a competitive industry. At the present time the most equitable such system appears to be to continue allotting the money to the Federal Government in the form of taxes and to have the Government continue to reinvest a suitable portion of that income in the basic research needed to sustain the economy.

REFERENCES

1. "Ground-Based Astronomy: A Ten-Year Program," National Academy of Sciences-National Research Council, 1964.
2. "Chemistry: Opportunities and Needs," National Academy of Sciences-National Research Council, 1965.
3. "Physics: Survey and Outlook," National Academy of Sciences-National Research Council, 1966.
4. National Planning Association, Economic Projection Series, Report No. 68-N-1.
5. Bureau of Census, Population Estimates, Series P-25, No. 381, December 18, 1967.
6. Annual Survey of Federal Funds for Research, Development, and Other Scientific Activities, Vol. XVIII, Table C-97, NSF 69-39, January 1970.
7. Economic Report of the President, January 1969.
8. "Toward A Public Policy for Graduate Education in the Sciences," National Science Board, 1969, NSB 69–1.
9. "Career Patterns Report No. 2, Careers of Ph.D.'s," National Academy of Sciences-National Research Council, 1968.

U. S. GOVERNMENT PRINTING OFFICE : 1970 O - 373-722

NATIONAL SCIENCE BOARD

PHILIP HANDLER (Chairman, National Science Board), President, National Academy of Sciences
E. R. PIORE (Vice Chairman, National Science Board), Vice President and Chief Scientist, International Business Machines Corporation

R. H. BING, Rudolph E. Langer Professor of Mathematics, The University of Wisconsin
HARVEY BROOKS, Gordon McKay Professor of Applied Physics and Dean of Engineering and Applied Physics, Harvard University
MARY I. BUNTING, President, Radcliffe College
H. E. CARTER, Vice Chancellor for Academic Affairs, University of Illinois, Urbana-Champaign Campus
WILLIAM A. FOWLER, Professor of Physics, California Institute of Technology
JULIAN R. GOLDSMITH, Charles E. Merriam Distinguished Service Professor and Chairman, Department of the Physical Sciences University of Chicago
NORMAN HACKERMAN, President, The University of Texas at Austin
WILLIAM W. HAGERTY, President, Drexel Institute of Technology
CLIFFORD M. HARDIN, Secretary of Agriculture
ROGER W. HEYNS, Chancellor, University of California at Berkeley
CHARLES F. JONES, President, Humble Oil & Refining Company
THOMAS F. JONES, JR., President, University of South Carolina
***WILLIAM D. McELROY,** Director, National Science Foundation
JAMES G. MARCH, Professor of Psychology and Sociology, School of Social Sciences, University of California at Irvine
ROBERT S. MORISON, Professor of Biology and Director, Division of Biological Sciences, Cornell University
GROVER E. MURRAY, President, Texas Tech University
HARVEY PICKER, Chairman of the Board, Picker Corporation
MINA S. REES, President, The Graduate Division, The City University of New York
JOSEPH M. REYNOLDS, Boyd Professor of Physics and Vice President for Instruction and Research, Louisiana State University, Baton Rouge
FREDERICK E. SMITH, Professor of Resource Ecology, Graduate School of Design, Harvard University
ATHELSTAN F. SPILHAUS, President, Aqua International, Inc.
RICHARD H. SULLIVAN, Managing Director, American Book Publishers Council, Incorporated
F. P. THIEME, President, University of Colorado
VERNICE ANDERSON, Secretary, National Science Board

---

*Succeeded Dr. Leland J. Haworth as Director on July 14, 1969.

CONSULTANTS

LEO GOLDBERG, Higgins Professor of Astronomy and Director, Harvard College Observatory, Harvard University
GEORGE S. HAMMOND, Professor of Organic Chemistry and Chairman, Division of Chemistry and Chemical Engineering, California Institute of Technology
NELSON J. LEONARD, Professor of Organic Chemistry, University of Illinois, Urbana-Champaign Campus
VICTOR McELHENY, Science Editor, *Boston Globe*
LEONARD I. SCHIFF, Professor of Physics, Stanford University

NSB 70-1

NATIONAL
ACADEMY of
SCIENCES

NATIONAL ACADEMY of SCIENCES

WASHINGTON, D.C.
1969

Preface

The presentation that follows has evolved out of several efforts to present the somewhat complex story of the National Academy of Sciences and the National Research Council—what they are, and what they do. Since the Academy's principal mission is to respond to current needs of the Federal Government for advice and information, the picture is constantly changing and therefore difficult to bring into sharp focus. Nevertheless, it was felt that a brief historical background, accompanied by a description of some typical projects, would serve to give the interested inquirer the broad outlines, at least, of the purposes and functions of this institution, now well into its second century.

PHILIP HANDLER
President

"*And be it further enacted,* that the National Academy of Sciences . . . shall have power to make its own organization, . . . to provide for the election of foreign and domestic members, . . . and all other matters needful or usual in such institutions, and to report the same to Congress.

"And be it further enacted, that . . . the Academy shall, whenever called upon by any department of the Government, investigate, examine, experiment, and report upon any subject of science or art, the actual expense of such investigations, examinations, experiments, and reports to be paid from appropriations which may be made for the purpose, but the Academy shall receive no compensation whatever for any services to the Government of the United States."*

The above provisions of the Act of Congress establishing the National Academy of Sciences more than a century ago still define the role of the Academy as a national institution through which individual scientists and engineers serve their nation and their professions. From modest beginnings in 1863, the Academy has grown to a membership of more than 800. It provides, largely through its National Research Council, a structure of specialized boards, committees, and panels organized to deal with specific problems presented to it by a wide variety of government agencies and private organizations. In 1964 a sister academy, the National Academy of Engineering, was created within the corporate framework of the National Academy of Sciences to strengthen and extend the resources to include the engineering professions.

*Excerpted from An Act of Congress to incorporate The National Academy of Sciences approved March 3, 1863, by President Lincoln.

Reflecting the growth of science and technology, the tasks of the Academy have broadened in scope and significance relative to many areas of agriculture, medicine, transportation, and housing as well as in areas reflecting more directly the classic disciplines of the physical and life sciences. In keeping with the Academy's charter, leading specialists from the universities, industry, and government accept appointment without fee to provide advice and guidance on matters under consideration by more than 500 committees, which work in close cooperation with the major Federal departments, the Executive Office, and the Congress. These committees, in turn, are served by a resident staff of about 800.

Through its Office of the Foreign Secretary, the Academy maintains effective links with international science and the scientific institutions of many foreign nations, including those seeking to develop more fully their own competences in basic and applied science. Nationally, the Academy is linked to the major U.S. professional societies, which are represented in the National Research Council.

Contents

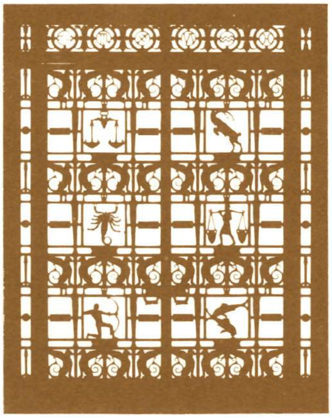
Reflecting the growth of science and technology, the tasks of the Academy have broadened in scope and significance relative to many areas of agriculture, medicine, transportation, and housing as well as in areas reflecting more directly the classic disciplines of the physical and life sciences. In keeping with the Academy's charter, leading specialists from the universities, industry, and government accept appointment without fee to provide advice and guidance on matters under consideration by more than 500 committees, which work in close cooperation with the major Federal departments, the Executive Office, and the Congress. These committees, in turn, are served by a resident staff of about 800.

Through its Office of the Foreign Secretary, the Academy maintains effective links with international science and the scientific institutions of many foreign nations, including those seeking to develop more fully their own competences in basic and applied science. Nationally, the Academy is linked to the major U.S. professional societies, which are represented in the National Research Council.

Contents

Academies of Science . . . a long tradition

The rise of modern science in the last three centuries has been accompanied in every major country by the formation of academies of science—a voluntary association of scientists for purposes of observation and experimentation, for the procurement of needed funds and instruments, for the publication of journals, and in general for the furtherance of science.



The U. S. Academy goes back to the Civil War . . .

In the United States the National Academy of Sciences was created in the midst of the Civil War as a result of a coincidence of motivations. There was first the desire on the part of the scientific community to create in the United States an academy of sciences that would play a role in this country similar to that performed by the academies of science in the great European nations.

The creation of the Academy stemmed not only from immediate practical problems of the Civil War, however, but more especially from the fact that, two and a half centuries after the establishment of the English colonies in North America, the United States was beginning to emerge as a technological society. An independent institution with close ties to the Federal Government was needed to muster the resources afforded by the nation's scientific community for guidance to a fledgling nation, rich in natural resources, in human spirit and inquiry but relatively poor in facilities and personnel for education and research.

The close relationship between the young academy and the National Government provided a unique opportunity both to the Government and to the nation's scientists to collaborate in the growth and development of the country's physical and intellectual resources.

. . . Membership is self-perpetuating

Academy membership is co-optative; that is, the current membership at any one time elects the persons who become new members. The Act establishing the Academy was amended in 1870 to remove the limitation of 50 on the total number of ordinary members. The number of new members that can be elected annually has recently been raised to 50.

Currently, the Academy consists of about 850 members and members emeriti and some 80 foreign associates. The delegated authority rests with the officers of the Academy, comprising the president, vice-president, home secretary, foreign secretary, treasurer, and twelve councilors elected by the members.

The basic organizational unit of the Academy is the section, to which members are assigned by their own choice. The present sections are: Mathematics, Astronomy, Physics, Engineering, Chemistry, Geology, Botany, Zoology, Physiology, Microbiology, Anthropology, Psychology, Geophysics, Biochemistry, Applied Biology, Applied Physical and Mathematical Sciences, Medical Sciences, Genetics.

To give greater flexibility to the election procedures, multidisciplinary classes were introduced by constitutional amendment in 1965: Class 1—Physical and Mathematical Sciences (members of the Sections of Mathematics, Astronomy, Physics, Chemistry, Geology, and Geophysics). Class 2—Biological and Behavioral Sciences (members of the Sections on Botany, Zoology, Physiology, Microbiology, Anthropology, Psychology, Biochemistry, Medical Sciences, and Genetics). Class 3—Engineering and Applied Sciences (members of the Sections on Engineering, Applied Physical and Mathematical Sciences, and Applied Biology). Nominations are originated (1) by intersectional proposal, (2) by the sections, (3) by temporary nominating groups appointed by the Council to consider persons from new or interdisciplinary fields, (4) by any voluntary group of 20 or more members, (5) by the Council itself.

The Academy got under way slowly . . .

During the first 50 years of its existence, the Academy grew rather slowly. From an initial 50, membership increased to approximately 200. Official requests for advice were sporadic and generally limited in scope. Scientific dependence on Europe continued although substantial progress was made in establishing new centers of learning and research.

The Academy did, however, have a significant part in helping the Federal Government to create or relocate departments and bureaus related to problems in scientific and technical fields. Thus, the Academy played an active role in relation to the Geological Survey, the Coast and Geodetic Survey, the Hydrographic Office of the Navy Department, the National Bureau of Standards, the U.S. Weather Bureau, and the Patent Office.

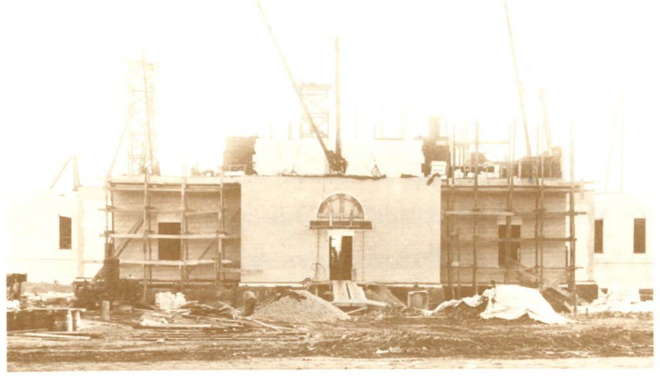
. . . but picked up momentum during World War I

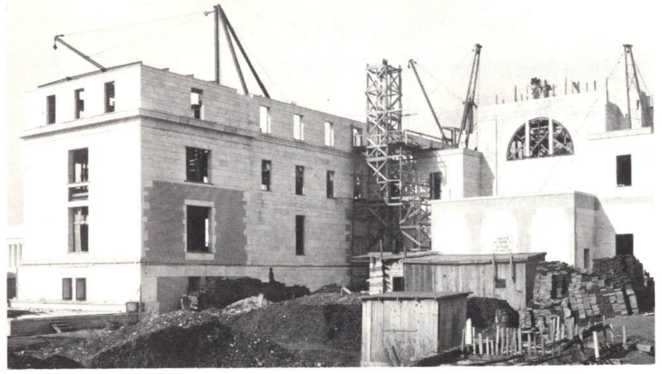
World War I had far-reaching effects upon the Academy. In one sense the changes resulted from the challenges presented by the war. In a larger sense, however, they were delayed reflections of the rapid growth of science and engineering that had taken place since the founding of the Academy. During this period, the nation's universities, both private and public, had grown and matured, producing an increasing number of well-trained scientists and engineers. With the introduction of the graduate school into American education, scientific research began to play a major role in universities such as The Johns Hopkins University and the University of Chicago. American industry had begun to adopt a scientific base; several of the larger industries established research laboratories of international repute near the turn of the century; and the Federal Government now had a number of science-based agencies.

The National Research Council is created . . .

In 1916, the war in Europe became the immediate stimulus that prompted the creation of a new organizational entity—the National Research Council—under the National Academy of Sciences, which was destined greatly to extend and enlarge the role of the Academy in public affairs. This development was the brainchild of George Ellery Hale, a notable solar physicist, organizer, and administrator, who unquestionably had greater impact on the organization of U.S. science in the first three decades of the twentieth century than any other individual. Hale felt that inevitably the United States would be drawn into the war and that its scientists should be mobilized in support of the war effort. He suggested to the president of the Academy,

Laying of the cornerstone, 2101 Constitution Avenue, October 30, 1922.





The Academy building under construction.

William Henry Welch, in mid-1915, that the services of the Academy be offered to the President of the United States to assist the nation in preparation for possible war.

Despite the multitude of wartime research problems that confronted the Research Council during its first two years, George Ellery Hale kept firmly in mind the idea of establishing it on a permanent basis. He foresaw that the growth and vigor of American commerce, industry, and agriculture would someday be closely related to the national effort in scientific research and development. Early in 1918 he wrote President Wilson to that effect, and the President was persuaded by his arguments. On May 11, 1918, the Executive Order perpetuating the National Research Council was signed by him.

. . . lending new strength to the Academy

The National Research Council broadened the base of the Academy by undergirding the body of elected members with a much larger organization representing a very wide cross section of the nation's scientists and engineers. It had the added advantage of a salaried staff that could more reasonably bear much of the burden of responsibility for providing a complex nation with advice in science and engineering. With this imaginative step, the leadership of the Academy overcame a shortcoming more or less common to academies of science, namely: their membership, although distinguished, is usually too limited in number to do full justice to the advisory needs of a nation or to be fully representative of the scientific and engineering community.

The determination of policy matters and the authority to engage in new enterprises rested, as before, in the membership of the Academy and its elected Council, and the members of the Academy continued to play an important role on the various advisory committees.

Members of the National Research Council are appointed by the president of the Academy upon nomination by the NRC-associated professional societies and the departments and agencies of the Federal Government. The membership also includes members at large, so that the Council not only derives strength from more than 150 leading professional societies as they have come into being over recent decades, but also acts as a center for inter-society activities whenever such action seems desirable.

In the half century since the National Research Council was created, its organizational structure has undergone some changes but the areas of concern have remained essentially the same. The divisions of the Council are: Behavioral Sciences, Biology and Agriculture, Chemistry and Chemical Technology, Earth Sciences, Engineering, Mathematical Sciences, Medical Sciences, and Physical Sciences. In addition, there are two offices that deal with problems common to all the divisions, the Office of Scientific Personnel and the Office of the Foreign Secretary of the Academy. Each division is under the direction of a chairman, appointed by the Council of the National Academy of Sciences (in the Division of Engineering, upon nomination by the Council of the National Academy of Engineering).

The work of the divisions is carried on largely through a number of committees appointed by the president of the Academy and administered by the divisions. At the present time, some 400 advisory committees, boards, and panels, with a combined membership of about 7,000 scientists and engineers, comprise the National Research Council.

The organization of the NRC provides for a chairman to be chosen by the Council of the Academy. From 1916 until 1954 the presidency of the Academy and the chairmanship of the Research Council were held by different persons. In June 1959 the Council of the Academy voted to name Detlev W. Bronk, specifically, as chairman of the National Research Council in addition to his position as president of the National Academy of Sciences. Later—in October 1962—the Council voted to establish as a general principle that both positions shall be held by the same person.

A new position, vice chairman of the National Research Council, was authorized by the Academy at its annual meeting in April 1966, and the National Academy of Engineering was invited to name one of its members to serve in that capacity. Clifford C. Furnas,* appointed by the NAE to fill a two-year term (February 1968 to February 1970), became the first person to serve in the new position.

The Academy serves without fee . . .

Although the Academy responds to many requests to render advisory services, and currently has a project budget in excess of $20 million to furnish advisory services on a cost basis, its charter precludes the acceptance of fees for its services. This restriction is entirely appropriate, for the Academy acts as an impartial adviser and moderator on scientific and technological matters related to the national interest. Provision is made, however, for the payment of travel and subsistence costs of advisers as well as the operating costs of committee secretariats.

The National Academy of Sciences was modestly funded before World War I. It lacked even a building of its own, and met in the Smithsonian Institution, whose hospitality dated back to the days of Joseph Henry. During World War I friends of the Academy decided that it should have its own home in Washington as well as an endowment that would give it both a significant degree of independence and means for taking some initiative in determining the course of its work. These friends presented to the Academy a gift of land at what is now 21st Street and Constitution Avenue, and the Carnegie Corporation of New York contributed $5 million for building and endowment. The latter gift, with its subsequent appreciations in monetary value was, until recently, the only source of unrestricted income.

. . . from the foundations, unrestricted funds

In 1967, in response to the Academy's appeal, the Rockefeller Foundation and the Ford Foundation responded generously with gifts of $1 million and $5 million respectively. Later in that same year, the Academy received grants from the Sloan Foundation in the amount of $1 million and from the Commonwealth Fund in the amount of $500,000.

President Seitz announced that the Academy would use the increased income from endowment funds in several ways: (1) to undertake vital new

Mme. Marie Curie and President Herbert Hoover in the doorway of the Academy, October 30, 1929.

---

*Deceased April 27, 1969.

programs that have not yet won popular support; (2) to underwrite the continuity and objectivity of its work through the independence offered by the immediate availability of unrestricted funds; (3) to strengthen the Academy's ability to accept a responsible and responsive role in its scientific and social environment, both nationally and internationally; (4) to improve the capability of the Academy staff to support and carry out new programs and tasks, and generally to facilitate the work of the divisions of the Research Council; and (5) to foster the growth and development of the Academy as an institution of broad purpose.

The need for endowment funds continues.

With growth, the need for greater space . . .

Need for additional physical facilities to accommodate the expanding activities of the National Academy of Sciences first made itself felt during World War II, when the Academy quickly outgrew the space at 2101 Constitution Avenue. By 1948, it had rented space in a number of office buildings throughout Washington to accommodate the staff involved in special advisory studies.

It responded further to its growing need for space by constructing two new wings to the main building, the east wing in 1962, the gift of the Equitable Life Assurance Society of the United States, and in 1965, the Physical Sciences and Engineering Wing, made possible by support provided by industry and several foundations. In order to bring together the scattered offices of the National Research Council, the Academy now occupies, on long-term lease from the George Washington University, the Joseph Henry Building, erected in 1966-1967 at the Academy's behest, at 21st Street and Pennsylvania Avenue, about one-half mile from the Academy headquarters. With the completion of its memorial auditorium—begun in 1968—as the final part of the quadrangle on Constitution Avenue, the Academy's physical plant will for the first time since World War II come close to meeting its needs.

. . . including a place for summer studies

In 1956 the Academy instituted, on a provisional basis, a summer study program at Woods Hole, Massachusetts, using the Little Harbour Farm estate of the Whitney family. The first study was in response to a request from the Navy for assistance in planning its anti-submarine research and development program and related matters for the next decade. The success of this summer session was such that other groups closely tied to the Academy requested similar services in subsequent summers. As a result, the Academy has maintained, on a continuing basis, a Summer Study Center at Woods Hole, which has served effectively in response to a variety of requests for use of the Center. Most of the studies conducted there are identified with a field or topic on which the Academy has an advisory committee.

Centennial Convocation of the National Academy of Sciences, October 22, 1963. Left to right: Jerome B. Wiesner, Science Adviser to the President; President John F. Kennedy; Detlev W. Bronk, President of the Rockefeller University and Chairman of the Centennial Committee; Frederick Seitz, President of the National Academy of Sciences.

The engineers establish their own academy . . .

The growing importance of engineering had long been recognized by the National Academy of Sciences. At about the time the National Research Council was being established, the membership structure of the NAS was reorganized to include an Engineering Section. The Research Council itself included first a committee on engineering, and following the Executive Order of May 11, 1918, a Division of Engineering and Industrial Research. Nevertheless, as the engineers continued to play an ever growing role in relation to national needs and problems, especially during World War II and afterwards, they began to feel the need for a separate but closely related Academy through which the nation's engineers, especially in industry, could respond effectively to those needs. They pointed out that the National Academy of Sciences, with a membership limited in numbers, could not be expected to be adequately representative of the large and diverse community of engineers.

Thus, slightly more than 100 years after the establishment of the National Academy of Sciences by Congressional charter, the National Academy of Engineering came into being under the original charter, and within the general organizational framework of the NAS. Officers headed by Augustus B. Kinzel, the first president of the NAE, were elected to serve for a term ending April 1966. Eric A. Walker, the second NAE president, was elected to succeed Dr. Kinzel.

The new National Academy of Engineering was established as an autonomous organization, parallel and coordinated with the National Academy of Sciences. Both academies avail themselves of the staff and facilities of the National Research Council. The program and objectives of the National Academy of Engineering are set forth in detail in its own literature.

Boards are responsive to large problems . . .

From time to time, large problems of a continuing nature suggest the need for a broader attack. In such cases, the Academy may appoint a board to oversee a structure of committees and panels operating within the board. Over the years many boards have exercised decisive influence in their respective areas, including the Food and Nutrition Board, the Drug Research Board, the Agricultural Board, and the Space Science Board, to name but a few. Recently, the Academy established three new boards in response to conspicuous national needs.

The NAS Board on Medicine was formed late in 1967 to help bring about wide-ranging improvements in the capacity of medical research and practice to meet national health needs. Reflecting the great importance the Academy attaches to problems in this area, the Board reports directly to the seventeen-member Council of the Academy.

Typical questions the Board has considered relate to: the quality and performance of medical care; how medical knowledge is used, kept up to date, and taught; the ethical and legal implications of human experimentation; and

the role of medical schools and other biomedical institutions in meeting the problems of rural and urban slums.

. . . computer sciences are interdisciplinary

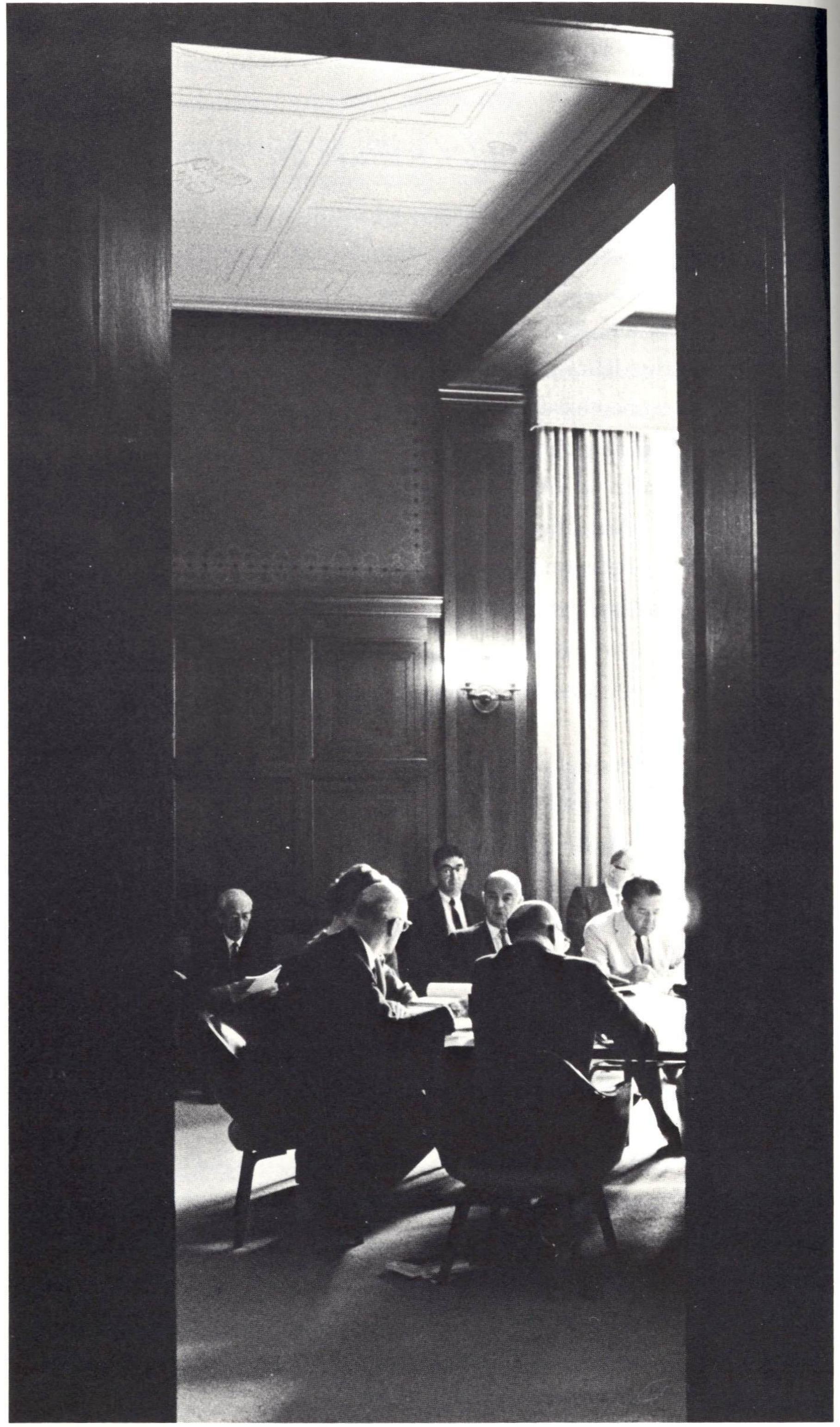
Responding to the increasing influence of computers on the individual and on society, the Academy established in mid-1968 a Computer Science and Engineering Board.

In announcing the formation of the new 12-member Board, President Seitz declared that its mission would be "to assess the complications of the enormous and somewhat heterogeneous growth of information processing technology as it affects the public and private sectors of our nation. It will be expected to take a broad view of this subject and of its applications to research and education in other branches of science and engineering as well as to the workaday needs of government, commerce, industry, and education." (The Board is supported by both private and governmental organizations.)

. . . as are environmental studies

In response to increasing national concern about the quality of the environment, the National Academy of Sciences and the National Academy of Engineering established an Environmental Studies Board early in 1967. In announcing the new Board, the presidents of the two academies declared that a major purpose was to provide a national focus for broad interdisciplinary efforts toward reducing or controlling pollution and other environmental problems. The Board also coordinates all activities of the two academies in this area and works directly with the legislative and executive branches of the Government in attacking related problems and in initiating broad new studies when necessary.

Five of the eight divisions of the National Research Council are currently studying problems directly concerned with pollution of the environment. Typical problems studied include potential effects of pesticide residues, food chemicals, hazardous materials, sonic boom, effects of low concentration of carbon monoxide, and behavioral science aspects of environmental change. Also relevant is the work of committees on water, atmospheric sciences, geography, food protection, and toxicology.



A meeting in the Board Room.

Most academies have similar functions . . .

The National Academy of Sciences, through the National Research Council, performs the functions common to most academies of science around the world. It renders a variety of services on behalf of the scientific community, such as the publication of journals and reports, the organization of symposia, the recognition and award of outstanding contributions to science. In the field of international science, where academies of science have traditionally played a strong role, the Academy has a wide variety of programs that include participation in international scientific undertakings, the development of working relationships with other academies, participation in the work of the international unions, cooperation in world-wide scientific undertakings such as the IGY, and—in recent years especially—assistance to developing nations in the fields of science and technology.

In an overall sense, the Academy is concerned with the continuing health and viability of science and its applications from the viewpoints of both the scientific community and society as a whole. Its continuing objectives, of course, are to encourage the acquisition of knowledge and to facilitate its use in the solution of the major problems that confront mankind.

. . . for the NAS a unique role

The National Academy of Sciences differs markedly from the academies of Europe in one very important respect, however, and that is in the nature and extent of its role as adviser to the Government. It does not maintain its own laboratories or direct research programs of its own, as do, for example, the four principal academies of the Federal Republic of Germany or the Academy of Sciences of the U.S.S.R. Because the advisory role of the Academy in the United States is in many respects unique and not too well understood, this aspect of its work is discussed here in some detail.

As indicated earlier, the charter from Congress declares in very general terms: That *the National Academy of Sciences shall, whenever called upon by any department of the Government, investigate, examine, experiment and report upon any subject of science or art . . .*

The Academy thus has a mandate to respond to requests for advisory services from the President of the United States, Congress, and the several departments and agencies of the Executive Branch. It may also take the initiative in bringing to the attention of the appropriate agencies of government problems affecting the national interest that science and technology could help to solve. The Academy may respond to requests for advisory services from private organizations as well as from the Federal Government.

The Academy advises on many problems . . .

The rapid growth of science and technology in the period following World War II has greatly broadened the interface between science and technology and the national interest. In 1961 Professor G. B. Kistiakowsky, who had been Special Assistant for Science and Technology to President Eisenhower in 1959-1960, proposed that the Academy establish, on a continuing basis, a policy advisory committee composed of Academy members to study policy matters of national and international interest related to science and its applications.

. . . involving science and public policy

The Council of the Academy accepted Professor Kistiakowsky's recommendations and in 1962 established the Committee on Science and Public Policy (COSPUP) with a membership in which all sections of the Academy are represented. The committee's first study, initiated by the Academy itself and financed by the Population Council, was addressed to the problem of the uncontrolled growth of human population. Its first report, *The Growth of World Population*, dealt with social and economic factors as well as biomedical aspects. Following its appearance there was an increase in the Federal support of research in fertility regulation. This marked a change in attitude on the

part of the Federal Government, which had been reluctant to support or urge such work.

In 1964 the Academy accepted a Congressional request to provide continuing advice to the House Committee on Science and Astronautics through the Committee on Science and Public Policy. In fulfillment of that mission, COSPUP submitted two major reports to the House Committee: *Basic Research and National Goals* (1965), and *Applied Science and Technological Progress* (1967).

A function of COSPUP of special interest to the scientific community is the surveys of specific fields* of science with subsequent recommendations to the Federal Government of appropriate support levels and indentification of neglected and promising areas of research. Panels of experts have been appointed by the Committee on Science and Public Policy to survey and report upon a variety of fields including: ground-based astronomy, chemistry, physics, plant sciences, mathematics, and the life and behavioral sciences. Periodic revisions of these reports are contemplated.

. . . and the general welfare

The Committee on Science and Public Policy is a permanent, continuing group responsible directly to the President and the Council of the Academy. Other groups, some long-term but many *ad hoc* in nature, have been established within the divisions of the National Research Council in response to requests for advice on specific problems, particularly those involving technology and the general welfare. A few of the more recent ones are cited by way of illustration.

ALASKAN EARTHQUAKE

In 1964, Dr. Donald Hornig, Science Adviser to the President, formally asked the Academy to establish a committee to meet a request from President Johnson for a "comprehensive scientific and technical account of the Alaskan earthquake and its effects." This was the disastrous "Good Friday Earthquake" of March 27, 1964, which created such widespread death and devastation in Alaska. A 12-man committee was established under the NRC Division of Earth Sciences, and two and one-half years later it began to publish, one volume at a time, a 10-volume report covering not only the scientific and technical aspects of the catastrophe but "the human drama" as well. It

---

*See Appendix for list of reports.

is expected that this definitive report will prove as enduringly useful as the report of the Carnegie Institution of Washington on the 1906 San Francisco earthquake.

SONIC BOOM RESEARCH

In anticipation of problems that might arise in connection with the development of a supersonic air transport vehicle, the White House requested the Academy in 1964 to "... plan an expanded sonic boom program, specify the tests that may be desirable, monitor the program and analyze the data derived from the tests. . . ." The Academy's Committee on the SST-Sonic Boom, with a number of specialized panels, has been assisting the Government in the design of research experiments to yield meaningful data on the physical and psychological effects of sonic booms that might be generated by commercial supersonic transport aircraft.

INTERDISCIPLINARY PROBLEMS

When interdisciplinary problems arise, two or more divisions may cooperate by appointing committees to work together on their solution. For example, the Department of Housing and Urban Development turned to the academies for advice and help in developing its research and development program. Two parallel committees were established, the Advisory Committee on Urban Technology by the Division of Engineering and the Advisory Committee on Social and Behavioral Urban Research by the Division of Behavioral Sciences, to formulate recommendations regarding both the technical and social aspects of a long-term research and development program for the Department.

ADVICE TO THE MILITARY

The National Academy of Sciences has a long-standing tradition of science advisory services to the military. When it was established in 1863 its founding members expected, among other things, to advise the Government on scientific and technical questions pertaining to the conduct of the war. This expectation was not fully realized, partly because the Academy came into being so late in the war and partly because the Permanent Commission of the Navy Department, appointed earlier, performed many of the functions that the Academy might otherwise have been expected to perform. In the World War I period the Academy rose to meet the situation by creating the National Research Council in order to bring the whole broad range of the nation's scientific and engineering talent to bear on the war effort.

During World War II, the energies and activities of the National Academy of Sciences and the National Research Council were absorbed by the war

Photograph by Fritz Goro, courtesy of LIFE; © Time Inc.

Scientists examining core sample from ocean bottom, Project Mohole test drilling.

effort. Because the Academy as a private institution lacked adequate funding of its own, it was not equipped to act as an operating agency; that role was undertaken by the Office of Scientific Research and Development. Academy members were, however, actively involved in the organization of the OSRD and its programs. Many research projects, particularly in the fields of metallurgy, ordnance, and military medicine, were carried out by the divisions of the National Research Council under contract to the OSRD, which provided the necessary funds.

During the uneasy peace that followed, the Academy continued to play a significant advisory role in national security. Standing committees in the fields of undersea warfare, emergency planning, civil defense, military personnel supplies, as well as various aspects of military medicine enable the military services to benefit from the consultation of several hundred active research personnel. In addition, a number of large *ad hoc* studies have been undertaken to assist individual services in long-range planning.

For some projects, the NAS is especially suited . . .

Many of the projects undertaken by the Academy are of such a nature that the Academy is uniquely qualified to assume responsibility for them.

THE ABCC

An excellent example is the Atomic Bomb Casualty Commission, established in 1946 at the request of President Truman for the purpose of studying the effects on survivors of the atomic bombs that were dropped on Hiroshima and Nagasaki. It is also one of the few instances in which an Academy group directly performs research. With the consent and cooperation of the Japanese Government, the ABCC has been working in Japan for more than 20 years, interviewing survivors, maintaining medical histories, conducting autopsies with the permission of relatives, and in other ways assembling a detailed clinical record of the bomb effects on those who were within the radii of the two nuclear blasts. The Research and Study Clinics in Hiroshima and Nagasaki are operated by the Academy.

THE MEDICAL FOLLOW-UP AGENCY

Another long-term project is represented in the work of the Medical Follow-up Agency, in the Division of Medical Sciences, which makes research use of the medical histories of 22 million men who served in the Armed Forces during the first and second World Wars and the Korean War. A project of the Agency that has attracted widespread interest is the twin registry—a roster of 16,000 pairs of male twins compiled from the medical and vital statistics records of World War II veterans. The registry provides a major new resource for studying the relative influences of environment and heredity on chronic disease.

THE AASHO ROAD TEST

In an altogether different area, the Highway Research Board of the National Research Council has, since 1920, played a central advisory role in the planning of the national highway network. In 1958, at the request of the American Association of State Highway Officials (AASHO), the Board launched a two-year national highway test, carried out at a cost of more than $27 million. It was the largest such test ever undertaken and provided performance data that were useful not only in the construction of the Federal Interstate Highway System, but also as the basis for Federal highway cost allocation and user tax legislation.

TURN-AROUND TIME

In the broad field of maritime transportation, the Maritime Transportation Research Board exists, as its name implies, to stimulate, correlate and advise on research needs and applications. In 1957 the Board commenced a five-year study of factors affecting turn-around time of general cargo ships in the San Francisco Bay area. With cooperation from both the Longshoremen's Union and the Pacific Maritime Association, reports were produced showing how productivity could be increased and costs lowered without increase in expended energy. This study* had a catalytic effect on the negotiations between unions and shippers for a pioneering mechanization and modernization agreement.

PROBLEMS INVOLVING BIG SCIENCE

The advent of "big science," with its large appropriations, has caused the scientific community to fear that the location of major new facilities would become the subject of intense regional rivalries. When it became clear in 1964, for example, that continued U.S. progress in the field of high-energy physics would require the construction of a 200-BEV accelerator, the Academy took the initiative in attempting to head off the anticipated controversy regarding the site location. President Seitz called a meeting of the presidents of the universities most active in this field of research and a committee was

---

**San Francisco Port Study*. Maritime Cargo Transportation Conference, 1964. Two volumes: 158 pp. Pub. 1140A; 166 pp. Pub. 1140B.

formed which later became Universities Research Association, Incorporated. The corporation offered its services to the Government for the establishment and administration of the accelerator project at such time as it might be funded by the Congress. In the meantime, at the request of the Atomic Energy Commission, an Academy committee recommended to the Commission six possible choices of a suitable site. From these six, the AEC made its final choice of a site in Weston, Illinois.

The Academy reviews the progress of science . . .

The Academy itself sees as one of its own major responsibilities the continuous critical review of progress in science and engineering and the identification of developments that may offer potential solutions for national and international problems. A significant part of this process is the noting of gaps and the recommendation of appropriate measures for filling them.

In the years since World War II, particularly, the Earth, its seas, the skies, and the space beyond the skies have come under the Academy's surveillance. A good example is the field of oceanography, to which the Academy has directed its attention over the last four decades.

OCEANOGRAPHY

In May 1957, Detlev W. Bronk, then President of the Academy, named a Committee on Oceanography headed by Harrison Brown, Professor of Geochemistry at the California Institute of Technology. The committee, which received financial support and full cooperation from Federal agencies with relevant interests, produced a report, *Oceanography 1960-1970,* which set forth a 10-year program covering every phase of oceanographic science, technology, and education. The report stimulated much interest and activity in both the legislative and executive branches of the Government. The President's Science Advisory Committee considered and endorsed the objectives of the report and commended it for action to the newly established Federal Council for Science and Technology. Much of the current interest in oceanography, as well as ongoing programs being supported by Federal agencies, stem directly from the recommendations of the Brown Committee.

Foreign Secretary Harrison Brown (second from left) confers with U.S. and Philippine scientists on economic development.

It should be noted, moreover, that this committee built upon the foundations laid by two earlier Academy committees. The Bigelow Committee, appointed in 1927, made recommendations that resulted in the establishment and endowment of the Woods Hole Oceanographic Institution in Massachusetts, with funding from the Rockefeller Foundation. Facilities on the West Coast were also expanded by the construction of an important new laboratory on the campus at La Jolla, California. As a further result of the Bigelow Report, funds were available during the thirties for growth and expansion of oceanographic research and technology in sea warfare.

A second committee headed by Detlev W. Bronk in the post World War II period produced a new report, *Oceanography 1951,* but the long-range program it recommended could not be fully realized because of the Korean War. Oceanography received further great impetus from the International Geophysical Year program, which included many oceanographic studies.

ATMOSPHERIC SCIENCES

The Academy directed its attention toward another neglected field—the atmospheric sciences—when it established a committee on meteorology in 1956 under the chairmanship of Lloyd V. Berkner. This committee found notable deficiences in meteorological education in the United States and in manpower trained in that field. The committee's major recommendation—the establishment of a national facility for fundamental research and training in the atmospheric sciences—was realized when the National Center for Atmospheric Research was established at Boulder, Colorado in 1960 by a consortium of universities with support from the National Science Foundation. The Committee on Meteorology, which had been expanded and renamed the Committee on Atmospheric Sciences, also anticipated the growing potentialities for weather and climate modification and appointed a panel to consider problems in that area. A special committee was formed in 1968 to consider the general circulation, basic to any major advance in prediction or control. This is the U.S. Committee for Global Atmospheric Research Program.

ADVISORY ROLE IN SPACE

In the wholly new field of space research, the National Academy of Sciences has played a key advisory role since the beginning. Following its involvement with the International Geophysical Year and its initiation of the early satellite program (see pages 25 and 26), the Academy in 1957 established the Space Science Board which made recommendations with respect to the establishment of the National Aeronautics and Space Administration and has advised the Government on the scientific aspects of the space program since then.

For example, the Space Science Board, after an extensive study, issued a report, *National Goals in Space, 1971-1985,* recommending that after the manned landing on the moon attention be focused on unmanned planetary exploration with early emphasis on Mars. A supplementary study of comparable scope was held at Woods Hole in 1965 and led to a definitive report, *Space Research: Directions for the Future.* Other major studies have dealt with radiation, physiology, exobiology, the inner planets, and the physics of near space. The Board has looked at such problems both from the approaches of those best achieved through ground-based devices and those possible only through space tools, as suggested in the study on ground-based planetary astronomy.

In 1968 the Academy, in cooperation with Rice University, agreed to help establish and to operate in its initial phases, the Lunar Science Institute. The purpose of the Institute, which will be constructed on a site adjacent to the Manned Spacecraft Center at Houston, is to provide a center for all scientists interested in lunar research, especially those concerned with lunar specimens. To this end, the Academy was requested, as a disinterested national organization, to serve as sponsor.

GEOPHYSICAL RESEARCH

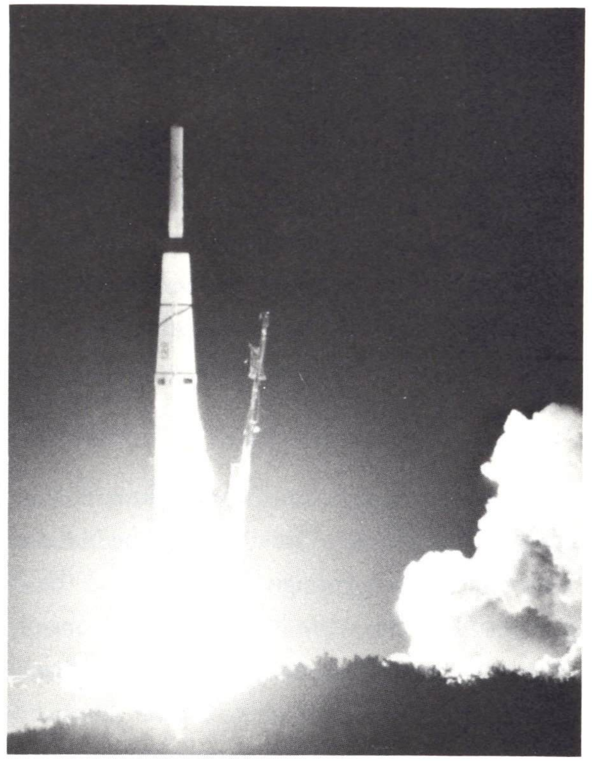
As early as 1919, the Academy had recognized that the geophysical sciences had a significant future in a nation that spanned a continent possessing highly diversified geological features. To stimulate and encourage interest in these fields, the Academy created the American Geophysical Union within its own structure. The AGU still retains its ties with the Academy, but over the years it has grown increasingly autonomous. Membership, initially limited to 65, is now about 9,000 and embraces a dozen or so fields.

In 1960 the Academy established a Geophysics Research Board to pursue opportunities that had evolved during the IGY and which were being sponsored internationally by the ICSU. These activities included the Years of the Quiet Sun (1964-1965), the Years of the Active Sun (1969-1970), the Upper Mantle Project (see page 26), and the international exchange of geophysical data through the ongoing ICSU World Data Centers. Plans are also under way for participation in international endeavors in the early '70s concerned with solar-terrestrial research and with the solid Earth. Another function of the Board is to integrate the various geophysical activities throughout the NAS–NRC. Several committees in the Earth Sciences Division, as well as the Space Science Board of the Physical Sciences Division, are concerned with the ways in which knowledge of the physics of the earth can be enhanced through the use of instrumentation, either now in being or potentially available. Recently developed instruments, with almost limitless potentials for research in the earth sciences and in agriculture as well, are the multispectral reconnaissance devices now being employed on high-flying aircraft and orbiting spacecraft for the remote sensing of agricultural and geophysical features of the earth. Among the advantages are speed, which makes possible almost simultaneous coverage of the entire globe; latitude, which provides synoptic coverage of large areas and, in some cases, costs lower than those of more conventional techniques. Such devices are potentially important in oceanography for measuring surface water temperatures in large areas; in volcanology for detecting incipient volcanic activity; and in structural geology for penetrating sky cover and haze by the use of radar bands. The geographers are finding many other uses for these devices in such areas as energy and water balance, vegetation and soils, mapping, geomorphology, and glaciology. The Board has produced several reports to guide the field.

Science is strongly international . . .

International cooperation is one of the oldest and strongest traditions of the scientific community. The officers of the National Academy of Sciences have always included a Foreign Secretary, and the Academy has been an active participant in the international organizations of science, of which the most important is the International Council of Scientific Unions. The Academy serves as the body through which the United States adheres to 25 international scientific unions and participates in the work of the ICSU and its 15

Members of the Committee on the Alaska Earthquake view a portion of Turnagain slide, south of Anchorage, August 1964.



Launch of Lunar Probe No. 2, October 11, 1958, during International Geophysical Year.

constituent unions as well as other major international councils and undertakings.

THE IGY

In recent years, particularly, a number of major scientific undertakings have been made possible by the cooperative efforts of many nations operating on a global basis. The most significant of these, and one that has since given rise to similar efforts in other fields, was the International Geophysical Year, lasting from July 1, 1957 through December 31, 1958. This 18-month period was devoted to the world-wide study of the phenomena of geology, oceanography, glaciology, meteorology, astronomy, and many other fields. The International Council of Scientific Unions, through its Special Committee for the IGY (Comité-Spécial de l'Année Géophysique Internationale, or CSAGI), planned and directed the over-all effort, and the individual academies of sciences were responsible for developing the programs for their respective nations. The U.S. National Committee for the International Geophysical Year, formed by the National Academy of Sciences, worked with the National Science Foundation and other private and public agencies to develop and carry out the U.S. part of the program.

Much notable work was done in all the fields of geophysical research, but the programs that attracted the greatest public interest were the earth-circling satellite program and the Antarctic research program. The earth-satellite program, in which the Russians successfully launched their Sputnik, and in which the inauspicious beginnings of our own Vanguard were followed by the highly successful Explorer program, was the direct progenitor of the present far-flung space program.

THE ANTARCTIC TREATY

During the IGY, some dozen or more nations participated in the establishment of scientific stations and observation posts at strategic places in Antarctica for the purpose of making a wide variety of observations of geophysical phenomena on the frozen continent. This vast cooperative effort, continuing on into the post-IGY period, led to the Antarctic Treaty, which had the effect of converting the whole of Antarctica into a scientific laboratory. The Treaty, which was signed by 12 nations at Washington on December 1, 1959, provides that Antarctica shall be used for scientific purposes only. Military installations and the testing of weapons are totally prohibited. The Treaty encourages freedom of scientific investigation such as prevailed during the IGY and provides specifically for the exchange of scientific personnel between expeditions and stations, and for the exchange of the results of Antarctic scientific research and observation.

OTHER WORLD-WIDE INTERNATIONAL PROGRAMS

The success of the IGY and its related programs prompted scientists in other fields to plan similar world-wide efforts. The International Biological Program (IBP) was voted into being in 1963 by the Tenth General Assembly of the International Council of Scientific Unions. United States participation was organized by the U.S. National Committee on IBP under the National Academy of Sciences. Working through a number of subcommittees, the U.S. National Committee for the IBP has organized programs around such topics as: productivity of terrestrial communities; production processes; conservation of ecosystems; productivity of freshwater communities; productivity of marine communities; human adaptability; use and management of biological resources.

In still another area, some 52 countries are now participating in the International Upper Mantle Project, an intensive program of research on the solid Earth. The International Union of Geodesy and Geophysics, which proposed the coordination of various studies of the continents and ocean floors at its XIIth General Assembly in 1960, is sponsoring the project with the cooperation of other international unions. The United States program is being directed by the U.S. Upper Mantle Committee (an NAS committee of the Geophysics Research Board established in mid-1963).

This world-wide undertaking has had three major phases: Phase I, an organization period (1962-1964). Phase II, an "operational period" (1965-1967) of activity in the programs emphasized by the IUMC: 1) multi-discipline (geophysical-geochemical-geological) regional studies, including terrestrial and oceanic geotraverses; 2) deep drilling for scientific purposes; 3) studies of the world rift system; 4) studies of continental margins and island arcs. Phase III, a final phase (1968-1970) to permit analysis of data and the interpretation and reporting of results.

The International Hydrological Decade (1965-1975) is a global program developed in response to growing world concern for the rapidly increasing problems of water planning and management. It is being coordinated by UNESCO. American hydrologists, in collaboration with the Federal Council for Science and Technology, originated the idea, which was carried forward by the National Academy of Sciences–National Research Council, the American Geophysical Union, and the International Association of Scientific

Hydrology. The U.S. Department of State transmitted it to UNESCO, and international planning meetings, under its auspices, were held in 1963 and 1964. Nearly 100 nations are participating. The major components of the U.S. International Hydrological Decade program are: 1) large-scale water and water-borne materials balances; 2) river, lake, and ground-water systems; 3) hydrological processes and techniques; 4) education and training; and 5) supportive and coordinating services. A project of special interest is the joint U.S.-Canadian study of the problems of the Great Lakes, International Field Year of the Great Lakes.

INTER-ACADEMY EXCHANGE AGREEMENTS

Science makes an important contribution to international understanding and good will through its ability to transcend political differences and to keep channels of communication open. This has been true throughout the last several centuries and at no time has science played this role more significantly than in the years since World War II.

Through a series of Inter-Academy Exchange Agreements, the National Academy of Sciences and the Soviet Academy of Sciences have sponsored exchange visits for scholars of their respective nations for purposes of study and research. The first such agreement, undertaken in 1959, was the Bronk-Nesmeyanov Agreement, named for the presidents of the two academies, Detlev W. Bronk and A. N. Nesmeyanov. With some short-lived interruptions, the program has been operating successfully for nearly a decade now; since 1966 similar exchange agreements have been signed with the academies of Yugoslavia, Poland, Czechoslovakia, Romania, and Hungary.

SCIENCE DEVELOPMENT PROGRAMS

One of the urgent needs of a developing nation is to evolve a technology of its own that will strengthen its economy and help it to become self-sufficient. The National Academy of Sciences, usually at the request of its own or another government, has been engaged in a series of studies designed to meet the needs of emerging nations. In 1958, for example, at the request of the International Cooperation Administration, a study was made to determine ways in which science and technology could be used more effectively in programs of assistance to the regions of Africa lying south of the Sahara and north of the Republic of South Africa. Later a successor group, the Africa Science Board, was created to carry out various scientific projects and to establish liaison with African scientific organizations. This group is now the Africa Panel of the Board on Science and Technology for International Development, which has recently been created to accommodate such programs within the Office of the Foreign Secretary of the Academy.

A comparable effort in another part of the world is the Joint Committee on Science Cooperation established in 1964 by the National Academy of Sciences and the Academia Sinica of Taiwan to strengthen scientific competence in the Republic of China.

In the Western Hemisphere, a Latin America Science Board was created in 1963 to provide advice, upon request, to the U.S. Coordinator of the Alliance for Progress. Since its founding, the Board has developed recommendations in agriculture, forestry, marine resources, engineering, anthropology, demography, and public health. This Board is now the Latin America Panel of the larger Board on Science and Technology for International Development.

Autumn Meeting on the campus, University of Washington, 1965.

The Academy serves the scientific community . . .

In addition to responding to requests for advice from public and private groups, the Academy is continuously engaged in informational and representational activity on behalf of the scientific community. Such tasks include: the publication of professional journals and reports for scientists and the lay public; the organization of symposia; the convening of appropriate gatherings in honor of distinguished visitors, and the granting of suitable awards to distinguished scientists and engineers.

SCIENTIFIC INFORMATION

The Academy functions in a dual role in relation to scientific information: on the one hand, as producer and distributor, and, on the other, as adviser to the scientific community on procedures and techniques in the management of information produced by scientific research. The scientific information resulting from the activities of the academies takes the form of scientific and technical reports, monographs, abstract journals, reviews, handbooks, and directories. Many are produced as the result of continuing studies, conferences, symposia, and special summer studies. [See list of representative reports in Appendix.]

For more than 50 years, the Academy has published the *Proceedings* in which members, and scholars sponsored by members, announce the results of recent research.

CONFERENCES AND SYMPOSIA

Topics of Academy symposia, selected at random, suggest the breadth of its concerns: world food supply, underwater physiology, photosynthesis, problems in space research, environmental health, hyperbaric medicine, insect behavior, highway research, radio sciences, problems of drug dependence, organ transplants, desalination, performance concepts in building, radiation research, permafrost, pest control. Many of these have resulted in published reports. In the course of an average year the NAS-NAE-NRC publishes approximately 150 reports.

DOCUMENTATION

Academy activities with respect to the mounting volume of scientific literature as a whole are numerous and varied. A Committee on Symbols, Units and Terminology, for example, coordinates the recommendations and views of major U.S. scientific and technical organizations concerned with the standardization of symbols, units, and nomenclature.

Through the Office of Documentation, the Academy participates in the international effort to direct documentation management toward the most efficient methods for the dissemination, storage, and retrieval of scientific information. At the request of the National Science Foundation, all existing notation systems for the storage and retrieval of information relating to chemical structure were studied; and the report* that resulted provides information about the applicability of modern methods to the handling of massive volumes of chemical information.

"SATCOM"

In 1966, the two academies organized—again with National Science Foundation sponsorship—a Committee on Scientific and Technical Communication (SATCOM). This group provides, outside the Government structure, a forum and clearinghouse of ideas for the scientific community generally, and parallels the Committee on Scientific and Technical Information, which provides for the agencies of the Federal Government.

"ILAR"

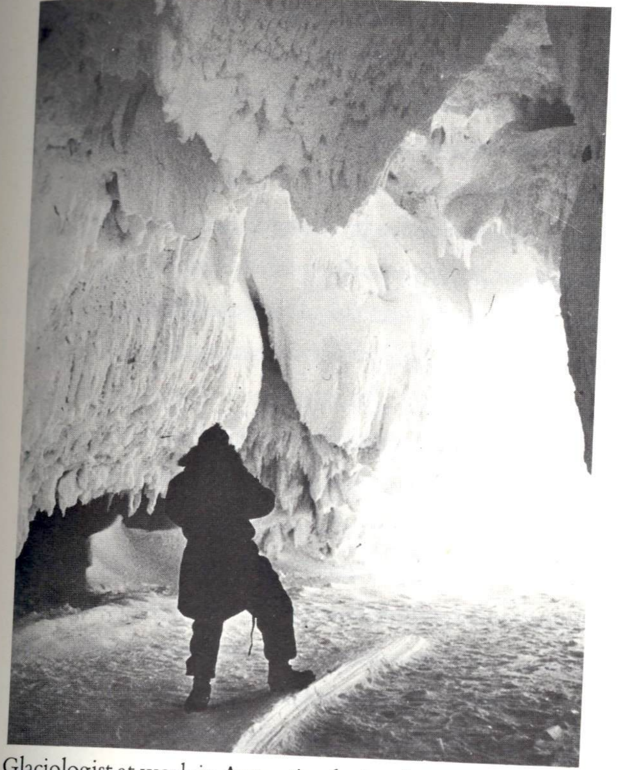
Still another highly specialized service to science is rendered by the Institute of Laboratory Animal Resources (ILAR) of the NRC Division of Biology and Agriculture. The Institute was established in 1952 when it became apparent that both the supply and the quality of laboratory animals was far below what would be needed to meet the rapidly expanding research needs in the life sciences. The Institute now includes committees that deal with such problems as professional and technical education, standards of animal care (including crating and shipping), sources of laboratory animals, animal research in gerontology, laboratory-animal literature, nomenclature for random-bred animals, and research utilization of uncommon animals.

Basic to all is the training of scientists . . .

The training of scientists in adequate numbers to meet a growing and varied demand is fundamental to continuing progress in science. It is, of course, impossible to "train" the truly creative scientist, but it is possible to provide the financial support and the environment that help such people to reach their highest levels of creativity. The numbers in this group will always re-

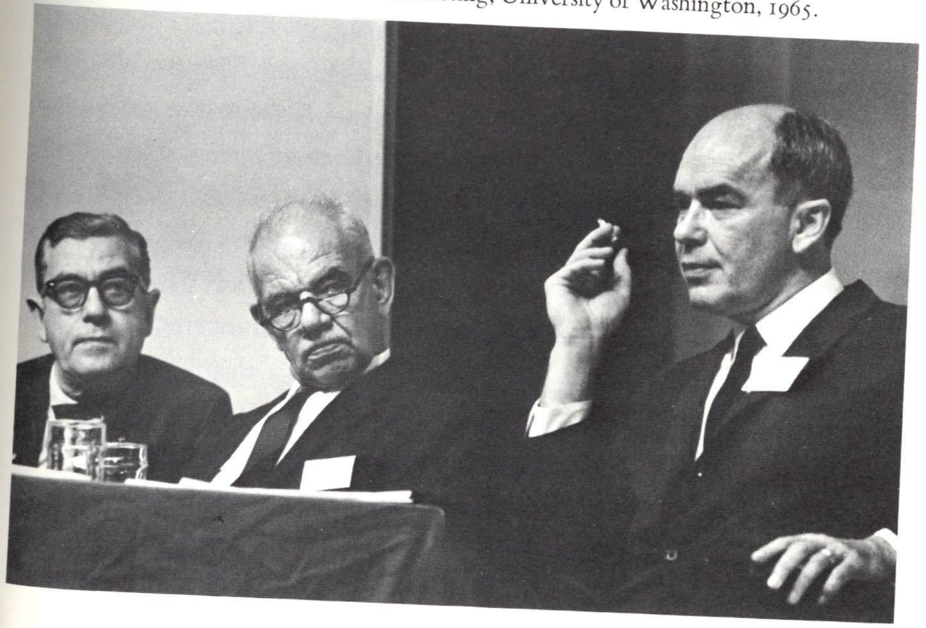
---

*Division of Chemistry and Chemical Technology. *Survey of Chemical Notation Systems.* Pub. 1150, 1964, 472 pp.



Glaciologist at work in Antarctica during the International Geophysical Year.

James A. Shannon, Director, National Institutes of Health; Leland J. Haworth, Director, National Science Foundation; and Donald F. Hornig, Science Adviser to the President, participating in symposium at Autumn Meeting, University of Washington, 1965.



main small in relation to the total population, as is true in other fields of creative endeavor. Over and above this group, moreover, it is necessary to provide opportunity for many thousands of scientists and engineers to be well trained to the doctoral level and beyond and for many technicians to be brought along to support and reinforce their efforts.

For more than half a century, the Academy has fostered activities directed toward strengthening and improving the nation's reservoir of trained scientists and toward the maintenance of systematic data that provide insight as to where this nation stands with respect to a critical national resource.

FELLOWSHIP PROGRAMS

In 1919, the Academy, with financial support from the Rockefeller Foundation, launched the National Research Council Fellowships. These fellowships made available to outstanding new PhD's in the sciences opportunities to conduct postdoctoral research at top-rank academic institutions before taking up the more routine tasks of academic or industrial careers. Coming at a time when this country was just beginning to concentrate on basic research, the fellowships enabled a new generation of scientists to absorb the best traditions in such research in whatever part of the world these might be found. It has been said that the present standing of the United States among the leading nations in scientific research owes as much to the National Research Council Fellowships (1919-1952) as to any other single factor.

In the period following World War II, when it was obvious that there would be severe manpower shortages in both engineering and science, several Federal fellowship programs came into being, of which the largest and most important was that of the National Science Foundation. An NSF program of scholarships and fellowships had been one of the strong recommendations of Vannevar Bush's report, *Science, the Endless Frontier*. The Foundation turned to the Academy and its Office of Scientific Personnel to administer the fellowship-selection process. During almost two decades the Office of Scientific Personnel has screened many thousands of applicants at predoctoral and postdoctoral levels and made recommendations to the Foundation for final selection.

The Academy has also entered into cooperative arrangements with other agencies of the Government for the administration of programs for research associates and for the exchange with other countries of students, scholars, and teachers. Through the Conference Board of Associated Research Councils, for example, the National Research Council has played an active role in recommending each year a list of candidates to receive grants to travel abroad and to lecture or do research under the Fulbright Program.

On behalf of the National Aeronautics and Space Administration and in cooperation with regional and national space organizations of other countries, the National Research Council administers a graduate and postdoctoral fellowship program for foreign scholars at a limited number of participating U.S. universities. In a similar way, it cooperates with the Agency for International Development to bring students to this country, particularly from the developing countries, with a view to their acquiring capabilities in the use of nuclear energy as a source of industrial power and for medical, biological, agricultural, and other processes. This program is under the general aegis of the International Atomic Energy Agency.

In this country, the Academy took the initiative in the early fifties in working with certain Federal agencies with large laboratories to develop programs that would make these facilities available for the training of promising young postdoctoral scientists. Such a program, it was agreed, would also benefit the laboratories by providing the stimulus of fresh young workers and a closer contact with university laboratories. The first program of research associateships was launched by the National Bureau of Standards in 1952, and by 1967 the Academy was administering similar programs for a dozen Federal laboratories.

MANPOWER DATA

In 1941 the Academy established the National Roster of Scientific and Specialized Personnel to provide the nation with a systematic source of information on highly qualified personnel. In the same year, and at the request of the National Defense Research Committee, the Academy created the Office of Scientific Personnel to carry out studies related to scientific and engineering manpower. The National Roster eventually became the National Register of Scientific and Technical Personnel, now maintained by the National Science Foundation. The Office of Scientific Personnel became an integral part of the National Research Council with responsibilities for administering fellowship and associateship programs in science and engineering, for carrying out manpower studies, and for conducting projects in the field of higher education that are of broad concern to the Academy and to the nation.

A project of special usefulness has been the establishment of large banks of manpower data, especially those concerning the holders of doctoral degrees. Covering a time span of more than 40 years and containing information about some quarter million persons, these data banks are a unique national resource. Properly maintained and expanded, they provide an unusual opportunity for extensive scholarly studies of trends in the various professional fields. Research based on these files has led to a series of published reports on such topics as the selection of fellows, PhD output of U.S. universities, and career patterns of PhD's in the sciences. The first comprehensive study of postdoctoral education in the United States was begun in 1966 by the Office of Scientific Personnel.

HUMAN RESOURCES AND SCIENTIFIC MANPOWER

Two major studies were initiated by the Office of Scientific Personnel under the sponsorship of the Conference Board of Associated Research Councils. In 1954 and again in 1965, the Conference Board named a Commission on Human Resources and Advanced Training to conduct studies under that general rubric. The 1954 study resulted in the volume, *America's Resources of Specialized Talent,** by Dael Wolfle, Director of the Commission. It provided one of the first integrated analyses of our national talent pool in areas related to science and engineering. The new Commission was charged with the task of examining current factors affecting supply and demand in the field of highly trained manpower in the United States. Under the leadership of John Folger, Dean of the Florida State University Graduate School, the Commission's findings were reported in 1967 and scheduled for publication late in 1969 by the Russell Sage Foundation.

A look forward . . .

As the Academy moved into its second century, several new patterns had become clear. An earlier concentration on problems within the various separate disciplines was giving way to an increasing involvement with broad-gauge problems affecting not only the entire scientific endeavor but technology and social institutions as well. Evidence was plain in the number and nature of the several multidisciplinary groups that had been established in parallel to the divisions of the National Research Council. The Committees on Oceanography and the Atmospheric Sciences, the Space Science Board, and the Environmental Studies Board suggest the kind of problems that cannot be met through the traditional disciplinary approach.

Of no less significance was the fact that as the Academy moved into new areas at the widening interface of science and society, its leadership had become increasingly aware of the need to establish closer and more effective working relationships with leaders in other professional fields. This has been accomplished in two major ways: (1) The Academy membership has recently been broadened to include scholars in certain of the social sciences, and the Research Council now includes among its affiliated societies those dealing with the disciplines of sociology, economics, history, and political science. (2) Membership in committees of the Research Council, which has long included medical practitioners, now frequently includes practitioners in law and management as well as researchers in a wide variety of interdisciplinary fields.

These trends have been dictated in large part by the growing concern within the Academy over the deleterious results of certain technological advances and the recognition that satisfactory solutions can come only through further technological progress and enlightened social and political leadership. The Academy's ability to move quickly into these new problem areas is owing to the generous support it has received—from several dozen government and

---

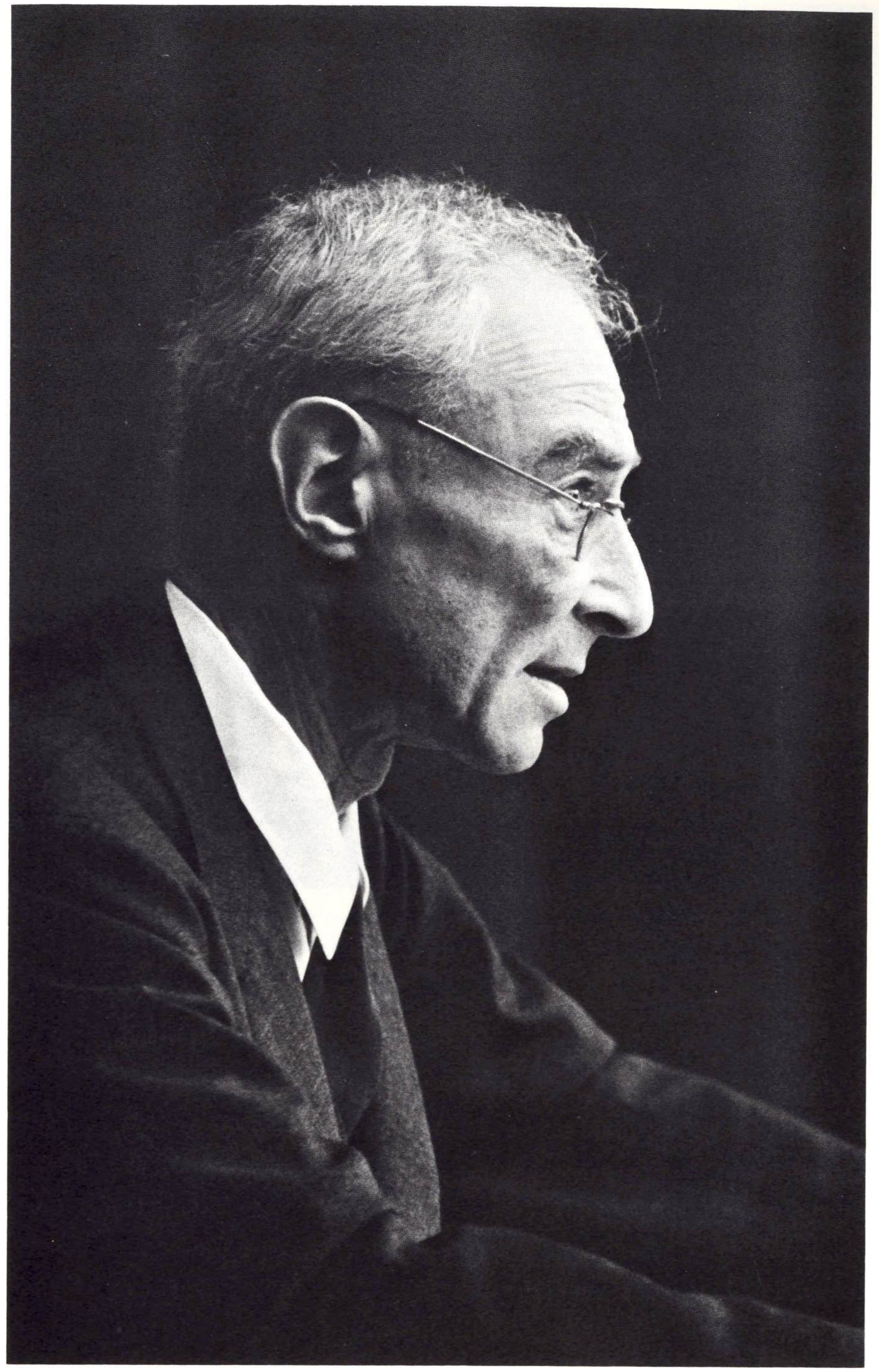
*Harper & Brothers, New York.

private agencies that share its concerns; to a small number of private foundations whose generosity has made it increasingly possible for the Academy to take independent initiative in nascent areas; to scores of sister academic and research institutions that willingly make available their most accomplished personnel; and to the many thousand individuals of great competence who voluntarily lay aside their own endeavors to do the work of the Academy and its associated National Research Council.

It would not be realistic to leave the impression that all the problems to which the Academy has addressed itself admit of ready solution. Sometimes months or even years elapse between the time an Academy committee makes a series of recommendations and action results that might be traced to those recommendations. Nevertheless, such seeming delays are part of the process by which critical issues make their way into the public consciousness. During these intervals there is time to build a constituency and to create a climate of public opinion. The success with which these ends are achieved rests solidly upon the professional stature and prestige of the advisory committees.

We have noted in the preceding pages that oceanography is a good example of a "neglected" field of research that required several committees and many years of effort to bring it into its own. In the area of population control, the Academy took a positive position when this vital subject was being shunned by governments generally and our own in particular. In the field of nutrition, where no one authoritative body of an official nature functions, the Food and Nutrition Board's recommended dietary allowances, first published in 1943, have come to be accepted as standard.

Thus the trials and efforts of the past, some successful and others less successful, point the way to the future and offer hope for the solution of some of the complex problems that vex our times.



"We have a modest part to play in history, and the barriers between us and the men of affairs, the statesmen, the artists, the lawyers, with whom we should be talking, could perhaps be markedly reduced if more of them knew a little of what we were up to, knew it with pleasure and some confidence. . . ." J. Robert Oppenheimer. The Centennial of the National Academy of Sciences, 1963.

The Joseph Henry Building, new home of the National Research Council.

"By their fruits . . ."

Much of the work of the National Academy of Sciences–National Research Council results ultimately in published reports, many of which enjoy wide circulation. The divisions and offices of the NAS-NRC have contributed the following lists of representative reports illustrative of the kind of tasks that are undertaken. The titles (some of which are out of print) represent only a fraction of the published works, which in over a century number in the thousands.

COMMITTEE ON SCIENCE AND PUBLIC POLICY

The Growth of World Population. Analysis of the Problems and Recommendations for Research and Training. Pub. No. 1091, 1963, 38 pp., paper, $1.00.

Federal Support of Basic Research in Institutions of Higher Learning. Pub. No. 1185, 1964, 98 pp., paper, $2.00.

The Growth of U.S. Population. Analysis of the Problems and Recommendations for Research, Training, and Service. Committee on Population, Pub. No. 1279, 1965, 25 pp., paper, $1.25.

Basic Research and National Goals. A Report to the Committee on Science and Astronautics, U.S. House of Representatives, by the National Academy of Sciences, March, 1965, 336 pp. (Out of print).

Applied Science and Technological Progress. A Report to the Committee on Science and Astronautics, U.S. House of Representatives, by the National Academy of Sciences, June, 1967. U.S. Gov't. Ptg. Off.,Washington, D.C., 434 pp., paper $1.50.

Ground-Based Astronomy, A Ten-Year Program. A Report Prepared by the Panel on Astronomical Facilities for the Committee on Science and Public Policy of the National Academy of Sciences. Pub. No. 1234, 1964, 105 pp., paper, $4.00.

**Chemistry: Opportunities and Needs.* A Report on Basic Research in U.S. Chemistry by the Committee for the Survey of Chemistry, National Academyof Sciences—National Research Council, Pub. No. 1292, 1965, 222 pp., paper, $5.00.

**Physics: Survey and Outlook*. A Report on the Present State of U.S. Physics and its Requirements for Future Growth, by the Physics Survey Committee, National Academy of Sciences-National Research Council. Pub. No. 1295, 1966, 119 pp., paper, $5.00.

The Plant Sciences Now and in the Coming Decade. A Report on the Status, Trends, and Requirements of Plant Sciences in the United States, by the Panel on the Plant Sciences for the Committee on Science and Public Policy, National Academy of Sciences. Pub. No. 1405, 1966, 167 pp., paper, $5.00.

Digital Computer Needs in Universities and Colleges. A Report of the Committee on Uses of Computers. Pub. No. 1233, 1966, 176 pp., paper.

**The Mathematical Sciences: A Report* by the Committee on Support of Research in the Mathematical Sciences of the National Research Council for the Committee on Science and Public Policy, National Academy of Sciences. Pub. No. 1681, 1968, 256 pp., paper, $6.00.

**The Mathematical Sciences: Undergraduate Education*. A Report by the Panel on Undergraduate Education in Mathematics of the Committee on Support of Research in the Mathematical Sciences of the National Research Council. Pub. No. 1682, 1968, 113 pp., paper, $4.25.

**The Mathematical Sciences: A Collection of Essays*. Edited by the Committee on Support of Research in the Mathematical Sciences with the assistance of George A. W. Boehm. Published for the National Academy of Sciences by The M.I.T. Press, Cambridge, Mass., 1969.

**The Behavioral and Social Sciences: Outlook and Needs*. A Report by the Behavioral and Social Sciences Survey Committee, 1969, 320 pp., case $7.95, paper $1.95. (Available from Prentice-Hall Inc., Englewood Cliffs, New Jersey.)

*See also the Divisions of Behavioral Sciences, Chemistry and Chemical Technology, Mathematical Sciences, and Physical Sciences.

DIVISION OF BEHAVIORAL SCIENCES

**The Behavioral and Social Sciences: Outlook and Needs*. A Report by the Behavioral and Social Sciences Survey Committee, 1969, 320 pp., case $7.95, paper $1.95. (Available from Prentice-Hall Inc., Englewood Cliffs, New Jersey.)

A Strategic Approach to Urban Research and Development, Social and Behavioral Science Considerations. A Report by the Committee on Social and Behavioral Urban Research, Pub. No. 1728, 1969, 100 pp., paper, $3.50.

A Program for Outdoor Recreation Research. A Report on a Study Conference conducted June 2-8, 1968, for the U.S. Department of the Interior, Bureau of Outdoor Recreation, Pub. No. 1727, 1969, 90 pp., paper, $3.00.

Behavioral Sciences and the Federal Government. A Report by the Advisory Committee on Government Programs in the Behavioral Sciences, Pub. No. 1680, 1968, 107 pp., paper, $3.50.

Communications Systems and Resources in the Behavioral Sciences. A Report by the Committee on Information in the Behavioral Sciences, Pub. No. 1575, 1967, 67 pp., paper, $2.50.

Behavioral Science Research in New Guinea. A Report of a Conference held August 18-25, 1965, sponsored by the Committee on Research in the Western Pacific, Pub. No. 1493, 1967, 141 pp., paper, $7.50.

---

*For the Committee on Science and Public Policy.

DIVISION OF BIOLOGY AND AGRICULTURE

An Evaluation of the Salmonella Problem. Publication No. 1683, 1969, 216 pp., $6.00.

Report of the Pesticide Residues Committee, June 1965.

Recommended Dietary Allowances, Pub. No. 1694, 1968, 101 pp., paper, $1.75. Latest in a continuing series initiated by the Food and Nutrition Board in January 1943 with No. 122, *Reprint and Circular Series*.

Pre-School Child Malnutrition, Pub. No. 1282, 1966, 355 pp., cloth, $7.50.

Principles of Plant and Animal Pest Control, Volume 1: *Plant Disease-Development and Control,* Pub. No. 1596, 1968, 205 pp., paper, $4.75.

Principles of Plant and Animal Pest Control, Volume 2: *Weed Control,* Pub. No. 1597, 1968, 476 pp., paper, $8.00.

Scientific Aspects of Pest Control, Pub. No. 1402, 1966, 470 pp., paper, $5.00.

Studies on Foot-and-Mouth Disease (*Estudios Sobre Fiebre Aftosa*), Pub. No. 1343, 1966, 180 pp., paper, $5.00.

Food Chemicals Codex, Pub. No. 1406, 1966, 846 pp., cloth, $25.00 (with supplements).

Standards and Guidelines for the Breeding, Care and Management of Laboratory Animals:

Chickens. ILAR Subcommittee on Avian Standards, Pub. No. 1464, 1966, 36 pp., paper, free.

Nonhuman Primates. ILAR Subcommittee on Primate Standards, Pub. No. 1677, 1968, 52 pp., paper, $2.50.

Cats; Dogs; Mice; Rats; Hamsters; Guinea Pigs; Rabbits. ILAR Committee on Standards, 1957-1966. (Standards are mimeographed separately.)

Use of Drugs in Animal Feeds. Proceedings of a Symposium, Pub. No. 1679, 1969, 407 pp., paper, $8.50.

DIVISION OF CHEMISTRY AND CHEMICAL TECHNOLOGY

Laboratory Planning for Chemistry and Chemical Engineering, Harry F. Lewis, Ed., Reinhold Publishing Company, New York, 1962, 536 pp., cloth, $23.00. (Out of Print).

Survey of Chemical Notation Systems, Pub. No. 1150, 1964, 472 pp., paper, $7.00.

High-Temperature Chemistry: Current and Future Problems, Pub. No. 1470, 1967, 98 pp., paper, $3.00.

Specifications and Criteria for Biochemical Compounds, Second Edition, Pub. No. 1344, 1967, 540 pp., cloth, $10.00.

Uses of Electronic Computers in Chemistry, Report of a Conference held at Indiana University, Bloomington, Indiana, November 1-2, 1965; January, 1967, 31 pp., paper, no charge.

Characterization of Macromolecular Structure, Pub. No. 1573, 1968, 410 pp., cloth, $15.00.

**Chemistry: Opportunities and Needs,* Pub. No. 1292, 1965, 222 pp., paper, $5.00.

Chemical Structure Information Handling. A Review of the Literature, 1962-1968. Committee on Chemical Information, Pub. No. 1733, 1969, 133 pp., $5.75.

---

*For the Committee on Science and Public Policy.

DIVISION OF EARTH SCIENCES

Water and Choice in the Colorado Basin. Committee on Water, Pub. No. 1689, 1968, 107 pp., paper, $2.50.

Alternatives in Water Management. Committee on Water, Pub. No. 1408, 1966, 52 pp., paper, $2.00.

The Science of Geography. Ad hoc Committee on Geography, Pub. No. 1277, 1965, 80 pp., paper, $2.50 (Out of Print).

Rock-Mechanics Research: A Survey of United States Research to 1965, with a Partial Survey of Canadian Universities. Committee on Rock Mechanics, Pub. No. 1466, 1966, 82 pp., paper, $3.00.

Drilling Thru the Earth's Crust. AMSOC Committee, Pub. No. 717, 1959, 20 pp., paper, $1.00.

The Disposal of Radioactive Waste on Land. Committee on Waste Disposal, Pub. No. 519, 1957, 142 pp., paper, $1.00 (Out of Print).

Thermal Considerations in Deep Disposal of Radioactive Waste. Committee on Waste Disposal, Pub. No. 588, 1958, 22 pp., paper, $1.00.

Correlation Charts. Committee on Stratigraphy. Eighteen charts published by the Geological Society of America. (Publication began in 1942.)

Time and Stratigraphy in the Evolution of Man, A Symposium sponsored by the Division of Earth Sciences, Pub. No. 1469, 1967, 97 pp., paper, $2.50.

Oceanography 1960-1970. Committee on Oceanography. Consists of 12 chapters, Washington, D.C., 1959.

DIVISION OF ENGINEERING

Science and Technology in Support of the Puerto Rican Economy. Prepared by the Committee on the Scientific and Technologic Base of Puerto Rico's Economy, February 1967, 89 pp., hard copy, $4.00, micro, $1.00.

Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee. Final Report of the Central Review Committee of the Summer Study on Space Applications, 1969, 34 pp., $2.00.

Report of the Ad Hoc Committee on Principles of Research-Engineering Interaction. Report prepared by an ad hoc committee of the Materials Advisory Board. Parts I and II, July 1966, 400 pp., $3.00.

Long-Range Aerospace Manufacturing Development. Three-volume Report prepared by the Committee on Aerospace Manufacturing Requirements of the Materials Advisory Board, 1968. Vol. 1, *Summary, Study Procedures and Discussion*, 66 pp., with Appendixes; Vol. II, *Base Metal Forms, Forming, Material Removal, and Joining*, 363 pp., with Appendixes; Vol. III, *Surface Conditioning and Treatment, Non-Metallic Fabrication, and Inspection and Evaluation Techniques*, 189 pp., with Appendixes, $3.00 each.

Tentative Skid-Resistance Requirements for Main Rural Highways. National Cooperative Highway Research Program Report 37, written by H. W. Kummer and W. E. Meyer, of Pennsylvania State University. Published by Highway Research Board, 1967, 80 pp., $3.60. [The National Safety Council has announced that the project on which this report is based has earned the Award of Merit of the Metropolitan Life Awards for Research in Accident Prevention as an outstanding contribution to safety in 1968.]

Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures. National Cooperative Highway Research Program Report 56, prepared by Donald T. Sutte, Jr., of Donald T. Sutte, Jr., and Associates, and Roger A. Cunningham, of the University of Michigan. Published by Highway Research Board, Pub. No. 1710, 1968, 74 pp., $6.40.

Long-Range Planning for Urban Research and Development, Technological Considerations, prepared by the Committee on Urban Technology, August 15, 1968, 53 pp., with Appendixes, A, B, C.

Permafrost: Proceedings of an International Conference. Building Research Advisory Board, Pub. No. 1287, 1966, 563 pp., cloth, $35.00.

Radiation Preservation of Foods, Proceedings of an International Conference, Boston, Massachusetts, September 27-30, 1964. Advisory Board on Military Personnel Supplies, Pub. No. 1273, 1965, 424 pp., cloth, $9.00.

Management of Lower-Extremity Amputees Using Immediate Postsurgical Fitting Techniques, prepared for the Prosthetic and Sensory Aids Service, U.S. Veterans Administration, by Ernest M. Burgess, M.D., Joseph E. Traub, and A. Bennett Wilson, Jr., with the cooperation of the Committee on Prosthetics Research and Development, 1966, 43 pp., with Appendixes, $0.45.

DIVISION OF MATHEMATICAL SCIENCES

**The Mathematical Sciences: A report*. Pub. No. 1681, 1968, 256 pp., paper, $6.00.

**The Mathematical Sciences: Undergraduate Education*. Pub. No. 1682, 1968, 113 pp., paper, $4.25.

**The Mathematical Sciences: A Collection of Essays*. Edited by the Committee on Support of Research in the Mathematical Sciences with the assistance of George A. W. Boehm. Published for the National Academy of Sciences by The M.I.T. Press, Cambridge, Mass., 1969.

Guide to Tables in the Theory of Numbers, Derrick Henry Lehmer. Bulletin No. 105, February 1941, 177 pp., paper, $3.00.

Handbook of Mathematical Functions. Committee on Revision of Mathematical Tables. National Bureau of Standards Applied Mathematics Series 55, 1964, 1060 pp., $6.50.

Guide to Tables in Mathematical Statistics. Committee on Statistics. Princeton University Press, 1962, 1014 pp., cloth, $8.50.

An Introduction to Traffic Flow Theory. Report of Special Committee on Publication of Selected Information on Theory of Traffic Flow. Highway Research Board Special Report 79. Pub. No. 1121, 1964, 149 pp., paper, $5.00.

*For the Committee on Science and Public Policy.

DIVISION OF MEDICAL SCIENCES

Accidental Death and Disability: The Neglected Disease of Modern Society. Committee on Trauma and Committee on Shock, 1966, 38 pp., paper, $0.35 (except in quantity).

Evaluation of Biomedical Research and Education in the Veterans Administration. Report to the

Office of Science and Technology by Advisory Committee on the Survey of Research in Education in the Veterans Administration, 1968, 75 pp.

Histocompatibility Testing. Report of a Conference and Workshop organized and carried out by Committee on Tissue Transplantation. Edited by Paul S. Russell, D. Bernard Amos, and Henry J. Winn. Pub. No. 1229, 1965, 192 pp., cloth, $6.00.

Postoperative Wound Infections: The Influence of Ultraviolet Irradiation of the Operating Room and of Various Other Factors. Report of Ad Hoc Committee of the Committee on Trauma. J. B. Lippincott Company, Philadelphia, supplement to August 1964 issue of *Annals of Surgery*, 192 pp.

"Proposal for a Certified Standard for Use in Hemoglobinometry: Second and Final Report," in *Blood* 13: 1101-1106, 1958.

"Statement on Normal (Whole, Pooled) Human Plasma," in *Transfusion* 8:57-59, 1968. (Editorial)

Effect of Exposure to the Atomic Bombs on Pregnancy Termination in Nagasaki and Hiroshima, by J. V. Neel and W. J. Schull in collaboration with R. C. Anderson, W. H. Borges, R. C. Brewer, S. Kitamura, M. Kodani, D. J. McDonald, N.E. Morton, M. Suzuki, K. Takeshima, W. J. Wedemeyer, J. W. Wood, S. W. Wright, and J. N. Yamazaki. Atomic Bomb Casualty Commission. Pub. No. 461, 1956, 241 pp., cloth, $2.00 (Out of Print).

Tropical Health: A Report on a Study of Needs and Resources. Pub. No. 996, 1962, 540 pp., cloth, $6.50.

IBRO Survey of Research Facilities and Manpower in Brain Sciences in the United States*. Committee on Brain Sciences, 1968, 314 pp.

---

*International Brain Research Organization.

DIVISION OF PHYSICAL SCIENCES

**Physics: Survey and Outlook*. Physics Survey Committee, Part 1, Pub. No. 1295, 1966, 119 pp., paper, $5.00; Part 2, Pub. No. 1295A, 1966, 165 pp., paper, $5.00.

Progress in Scientific Radio: Fifteenth General Assembly of the International Scientific Radio Union. U.S.A. National Committee of the International Scientific Radio Union, Pub. No. 1468, 1966, 371 pp., paper, $10.00.

Proceedings of the Third Symposium on Underwater Physiology. Sponsored by the NAS-NRC Committee on Undersea Warfare and the Office of Naval Research. The Williams and Wilkins Co., 1967.

Science in Antarctica Part I: The Life Sciences in Antarctica. Committee on Polar Research, Pub. No. 839, 1961, 162 pp., paper, $1.50.

Science in Antarctica, Part II: The Physical Sciences in Antarctica. Committee on Polar Research, Pub. No. 878, 1961, 131 pp., paper, $1.50.

Natural Resources (in 7 parts). Committee on Natural Resources. *Summary*, Pub. No. 1000, 1962, 40 pp., paper, $2.00.

Renewable Resources, Paul Weiss, Pub. No. 1000A, 1962, 127 pp., paper, $2.00.

Water Resources, Abel Wolman, Pub. No. 1000B, 1962, 35 pp., paper, $1.00.

Mineral Resources, Dean F. Frasche, Pub. No. 1000C, 1962, 32 pp., paper, $1.00.

Energy Resources, M. King Hubbert, Pub. No. 1000D, 1962, 141 pp., paper, $2.00.

Marine Resources, Sumner T. Pike and Athelstan Spilhaus, Pub. No. 1000E, 1962, 8 pp., single copies free, in quantity, $0.50 each.

Social and Economic Aspects of Natural Resources, Gilbert F. White, Pub. No. 1000G, 1962, 53 pp., paper, $2.00.

New Uses for Low Energy Accelerators. A report by the Committee on Nuclear Science, 1968, 173 pp.

Research in Solid-State Sciences: Opportunities and Relevance to National Needs. Pub. No. 1600, 1968, 103 pp., paper, $3.50.

Energy Systems of Extended Endurance in the 1-100 Kilowatt Range for Undersea Applications. Committee on Undersea Warfare, Pub. No. 1702, 1968.

The Feasibility of a Global Observation and Analysis Experiment. Committee on Atmospheric Sciences, Pub. No. 1290, 1966, 172 pp., paper, $4.00.

Conference on Transportation Research Summary, Pub. No. 840, 1960, 88 pp., paper.

Transportation Design Considerations, Pub. No. 841, 1961, 248 pp., paper.

U.S. Transportation: Resources, Performance and Problems, Pub. No. 841-S, 1961, 326 pp., paper.

Space Research: Directions for the Future. Space Science Board, Pub. No. 1403, 1966, 637 pp., paper, $7.50.

Solid-Earth Geophysics: Survey and Outlook. Geophysics Research Board and Division of Earth Sciences, Pub. No. 1231, 1964, 198 pp., paper, $4.00.

Waste Management and Control. Committee on Pollution, Pub. No. 1400, 1966, 257 pp., paper, $4.00.

---

*For the Committee on Science and Public Policy.

OFFICE OF SCIENTIFIC PERSONNEL

High School Ability Patterns—A Backward Look from the Doctorate, Lindsey R. Harmon, 1965, 74 pp.

Profiles of Ph.D.'s in the Sciences. A summary report on follow-up of doctorate cohorts, 1935-1960, Lindsey R. Harmon, Pub. No. 1293, 1965, 123 pp., $2.50.

Fourteen Years of Research on Fellowship Selection. A summary by Lindsey R. Harmon, Pub. No. 1420, 1966, 39 pp., $1.50.

Doctorate Recipients from United States Universities, 1958-1966. Sponsored by the National Science Foundation, Pub. No. 1489, 1967, 262 pp., $8.50.

Careers of Ph.D.'s—Academic Versus Nonacademic. Pub. No. 1577, 1968, 106 pp., $6.00.

The Backgrounds and Early Careers of Engineering Doctorate Recipients, Joan G. Creager. A Report to the Ford Foundation, 1968.

America's Resources of Specialized Manpower, Dael Wolfle. Report of the Commission on Human Resources and Advanced Training, Harper & Brothers, 1954, 332 pp., $4.00.

Education and Professional Employment in the U.S.S.R., Nicholas DeWitt. Sponsored by the National Science Foundation, NSF 61-40, 1961, U.S. Government Printing Office, 856 pp., $5.50.

Stipends and Spouses, James A. Davis, National Opinion Research Center for OSP. The University of Chicago Press, 1962, 294 pp.

OFFICE OF THE FOREIGN SECRETARY

Report of the Subcommittee on Travel to International Scientific Meetings, Advisory Committee on International Organizations and Programs, March 1967, 8 pp.

Report of the Committee on the Quality and Organization of International Scientific Meetings, June 1968, 9 pp.

Report of Conference on Agricultural Research Priorities for Economic Development in Africa. (English and French language versions, each in 3-volume reports, English, approx. 1,000 pp., French, approx. 1,200 pp., 1969.)

A Report on the Lembaga Ilmu Pengetahuan Indonesia-National Academy of Sciences, U.S.A., Workshop on Food held at Djakarta, Indonesia, May, 1968, 3 vols., Djakarta, 1968, 304 pp.

Philippines-U.S. Workshop on Fisheries and Oceanography, Manila, 4-9 December 1967, 150 pp.

Science and Brazilian Development. Report of a Workshop on Contribution of Science and Technology to Development, April 11-16, 1966, Itatiaia, Brazil, Part I, 39 pp.

Science and Brazilian Development. Report of a Second Workshop on Contributions of Science and Technology to Development, February 5-9, 1968, Washington, D.C., 102 pp.

Industrial Research in Brazil as a Factor of Development. Report of the Joint U.S.-Brazil Study on Industrial Research in Brazil, February 1969, 34 pp.