theory; and one simply has to accept the fact that the procedure is formal, and that no one has, or in the nature of things *can* have, a "physical interpretation" for the various quantities in the equations. For this desire for a "physical explanation" is, I believe, precisely a desire for a horizontal explanation when that procedure is inapplicable.

The yearning for "physical explanation" (which as far as I can see always means horizontal explanation) is an urgent one, which extends to all levels of sophistication in science. It is clear that Einstein never gave up the idea that physical interpretation of the unitary events of physics was both possible and desirable. There is a long list of earnest and able individuals who have been puzzled by "action at a distance," and who have sought some other model with macroscopic properties which would help them escape the, for them, intolerable fact that action at a distance is not "understandable" (although, curiously, action *not* at a distance presents equally grave difficulties). All of these persons have, in my judgment, not faced up to the nature of explanation. Vertical explanation has not been satisfying to them; and their concern has been with cases to which horizontal explanation is not applicable.

There remains, we must confess, an underlying mystery here. Why is it that the universe furnishes so many paired instances of useful isomorphism as long as the scale of events lies, roughly, between 10^{-8} centimeter and a few hundred thousand light years but recedes into completely special and unique abstractness when the scale is roughly 10^{-13} centimeter or smaller, or is as large as, say, a billion light years? Is this because our physical theories remain too anthropomorphic, influenced too much by the accident of our own size and by the illusion of continuity at macroscopic dimensions? Will we ever have the courage and imagination to leap over this barrier of smallness into the world of unitary events, and construct a theory which starts at the right place and with the right concepts? Such a theory will surely begin with no recognizable space and time variables, but will, at a much later stage, develop the traditional and continuous time and space measurements as statistical consequences, appropriate only on a macroscopic scale, of the discrete variables of the more basic theory. If and when such a theory is available, certain presently unsatisfactory aspects of the explanation of physical events will have disappeared.

I want to emphasize an aspect which the two types of explanation have in common. It is an aspect, moreover, which the scientist values very highly indeed, for both practical and esthetic reasons. Namely, either type of explanation addresses itself to an element of our experience and gives meaning to it, gives new significance and richness to it, suggests new usefulness for it, in short *explains* it, by placing it in a broader context. Horizontal explanation does this vividly, but narrowly. An electromagnetic wave is put into the context of more familiar mechanical or hydrodynamical waves on strings or ponds. Vertical explanation probes ever so much deeper into the isomorphism of phenomena and puts the case under study within the total context of all the possible phenomena which conform to all the relationships deducible from their common origin—namely, the postulates on the bottom step. The electromagnetic wave thus is placed within the broad context of all possible types of solutions of certain very general types of differential equations. All the practical and esthetic values which result from this recognition of relatedness constitute, I think, the important essence of explanation.

Reference

1. J. Bronowski, *Science and Human Values* (Harper and Row, New York, 1959).

Federal Support of Science: A Formula for Cooperation

National Academy Public Policy Committee offers suggestions for eliminating sources of difficulty.

The following are the formal conclusions contained in Federal Support of Basic Research in Institutions of Higher Learning, *a report issued this week by the National Academy of Sciences Committee on Science and Public Policy. A discussion of the report appears in News and Comment, page 1304.*

The commitment of large public funds for the support of basic research in universities has led not only to spectacular growth of the scope of scientific effort but also to advances in quality: American science has reached a position of world leadership. We attribute this in no small measure to enlightened policies of several federal agencies committed to furtherance of basic research; specifically to the current emphasis on support by research project grants and by fixed-price research contracts (not too unlike grants), coupled with an extensive use of advisory scientific bodies, such as panels or study sections, to select scientifically meritorious projects for support. We believe that research project grants and contracts should remain the backbone of federal policy in support of basic research in science in universities. The emphasis on large programmatic ventures and laboratories which has been manifest in recent times must not lead to a loss of emphasis on individual scientists: the individual investigator has been and will remain the source of strength in American science.

Concerning Federal Agencies

1. The criterion of selection for grant or contract support of basic research has

been primarily the scientific quality of the work proposed. The selection of projects on this basis has come about in various ways, but particularly as a result of the judgment of scientists well versed in the areas concerned. We believe this merit judgment should be retained as a prime basis for federal support. The methods of obtaining this merit judgment at present vary; the following measures will strengthen and bring greater effectiveness to the judging process.

(a) Federal agencies not presently using study sections or advisory panels for the merit rating of research proposals would improve the quality of their research programs by the adoption of these or similar devices.

(b) Membership in the panels and sections should be on a relatively short-term rotating basis, and wide circles (in terms of scientific disciplines, geography, and function) of the scientific community should be tapped for this service. This is necessary because conscientious service on such panels is very costly in time to consulting scientific personnel. Moreover, we are convinced that infusion of new blood into the sections and panels is conducive to the maintenance of high scientific standards and helps to induce the selection of the most original and promising research proposals.

(c) When panel, section, or consultant activity has resulted in ordering of proposals by scientific merit, the order suggested should be seriously considered by the federal agency staffs and modified only in special circumstances which are explained to the panel or section members.

(d) Panels and sections should not be involved in detailed evaluation of proposed budgets, although panel judgments on the general reasonableness of proposed budgets should be seriously considered by agency staffs. Detailed budget considerations should be the responsibility of agency staffs alone. However, panel or section judgments as to the proper duration of grants or contracts should be given considerable weight by the agency staffs. While panels and sections must supply the primary judgments regarding scientific merit, questions of administrative responsibility and agency policy must be dealt with by full-time staff members, and the agency itself must assume responsibility for the final decisions with regard to awards of grants and contracts. For this reason, we strongly endorse the efforts of the government to improve the quality of the career service, by providing compensation at levels comparable with private salaries, and by encouraging staff members to continue their scientific and professional advancement.

(e) Consultation with scientific referees by mail is less satisfactory than the panel-section procedures. Where this procedure is used, however, it is essential to keep the referees informed as to the effect of their advice in each case. Failure to do so is bound to lead to less responsible attitudes among referees and in the end to purely administrative choices of projects. We do not believe that personnel whose main functions are administrative can for long retain keen judgment as to what is most promising in science. We believe, therefore, that purely administrative mechanisms for selection of worthy research proposals would lead to inferior programs and thus to a waste of public funds.

2. The advantages of grants generally outweigh those of fixed-price contracts for basic research. However, research contracts have been developed into legal instruments that place few restrictions on the principal investigator beyond those imposed by grant arrangements under present regulations. Unfortunately, there is a current trend toward introducing into grant and contract negotiations and regulations administrative restrictions that are inimical to effective basic research. We believe that this trend should be reversed, with the universities taking increasing responsibility for proper administration of grants and contracts.

3. We recognize and endorse the fundamental legal principle that public funds may be spent by contractors and grantees only for stated purposes, and thus that diversion of funds to other purposes cannot be tolerated. We welcome in principle the issuance of guidelines concerning the expenditure of grant and contract funds. But we discern a recent trend toward unnecessary restriction of scientific freedom and increases in the bookkeeping chores of scientists in both grants and contracts; we believe that this trend will result in lower returns on the investment of public funds in science.

4. The project proposal by an applicant states the purpose of the requested grant. The implications of this are not always understood by applicants. We believe that many difficulties could be avoided if the federal agencies, in their printed instructions for the preparation of research proposals, explained clearly the relation between the contents of a proposal and the purpose of the grant. Scientists should bear in mind in making application for grants that the preambles of their proposals define the purposes for which granted public funds may be spent. We believe that a project proposal should include:

(a) Broad objectives of the proposed research in terms of areas of scientific knowledge to be advanced.

(b) Specific early research objectives stated as illustrative of the broader aims.

(c) Scientific tactics (experimental methods) to be employed. We also hold that the grant or contract instrument should explicitly recognize the broad objectives (a) as its legal purpose. Only a deviation from the broad objectives of a project proposal, thus stated, should be considered as constituting a change

National Academy Public Policy Committee

The members of the committee are George B. Kistiakowsky, Harvard University, chairman; Lawrence R. Blinks, Stanford University; H. W. Bode, Bell Telephone Laboratories; Frank Brink, Jr., Rockefeller Institute; Melvin Calvin, University of California, Berkeley; Leo Goldberg, Harvard College Observatory; Frank L. Horsfall, Jr., Sloan-Kettering Institute for Cancer Research; A. L. Lehninger, Johns Hopkins University; Donald R. Lindsley, University of California, Los Angeles; Saunders Mac Lane, University of Chicago; William W. Rubey, University of California, Los Angeles; Harry L. Shapiro, American Museum of Natural History; T. M. Sonneborn, Indiana University; Alvin M. Weinberg, Oak Ridge National Laboratory; Robert E. Green, National Academy of Sciences, committee executive secretary; A. Hunter Dupree, University of California, and Don K. Price, Harvard University, consultants.

in the purpose of the grant, thus calling for special approval from the federal agency.

5. Current regulations concerning the expenditure of grant moneys restrict the transfer of funds from one budgetary item to another. We believe that these regulations are quite proper insofar as they deal with the compensation of senior personnel, with travel (especially travel abroad), and with improvements in the facilities of the grantee institution. On the other hand, we believe that the principal investigator should be given maximum latitude in spending other grant moneys for the stated purpose of the grant as he sees fit.

Ordinarily, so much time passes between the preparation of a proposal and the expenditure of grant funds that preferred tactics change, new equipment becomes available, and so forth. We believe that the principal investigator should be free to shift funds between budget items of equipment and expendable supplies, and that a provision that the principal investigator explain the reasons for substantial shifts, in his application for renewal or continuation of the grant, would provide an adequate safeguard against misuse of grant funds. At the very least we urge that the present limit (usually $500) on purchase of initially unspecified equipment be increased in some proportion to the total value of the grant. Thus principal investigators will be spared a great deal of wasteful paper work to obtain, necessarily, either perfunctory approvals or arbitrary refusals from remote agency staffs.

6. The accounting for part-time service of principal investigators and other academic personnel in projects supported by research grants or contracts, whether or not such service is paid for with grant funds, must be realistically related to the input of professional effort on the project. We believe that accounting for research effort in terms of time input, i.e., in terms of days or hours, is unrealistic and can lead to fiscal policies that fail to make allowances for the nature of scientific research. We recommend that accounting for effort of professional personnel on a grant or contract be expressed in terms of some fraction of the total effort applied by the individual to his university duties.

The full fiscal year of a grant, or the full academic year, is recommended as the minimum period of time for which accounting of service should be made by a university. However, the time periods in which individual scientists have no university duties, such as summer vacations, may be accounted for separately.

7. We are not competent to enter into a detailed discussion of the problem of appropriate overhead costs. We believe, however, that inadequate provision for such costs is harmful to the universities as communities of scholars dedicated to the balanced education of American youth. We urge that overhead payments be provided for, on grants as well as on contracts, based on application of essentially the same formula in both instruments.

8. While we strongly endorse the project grant/contract system of research support, we believe that three auxiliary types of support are also necessary for the healthy growth of American science.

(a) The first of these are institutional or general research grants related to existing totals of project grants, now being made on too modest a scale by the National Institutes of Health and the National Science Foundation. These should be strengthened and broadened in purpose to overcome serious imbalances created in the universities by the growth of existing project research support and to meet the need for initial support of new projects.

(b) The second type is necessary to meet the problem of junior faculty members who have difficulties obtaining support for independent research. We believe that a system of small research grants—on a modest scale—should be introduced. These would be awarded to junior scientists for indivual research on the basis of a very general outline of their research interests, supported by letters of endorsement from senior scientists personally acquainted with the work of applicants. Aside from an agreed sum as reimbursement to the grantee institution for work of the applicant, the budget should provide only for supplies and smaller items of equipment, but should not be broken down into component parts. The grantee investigator should, within the purpose of the grant, be allowed to pursue such researches as appear most fruitful to him in the broad area defined in the application. Some truly original ideas and discoveries have come from young scientists, and we cannot afford to tie them to narrowly defined research objectives.

(c) The nation faces the problem, in addition to that of rapidly growing population, of an even faster-growing need for highly educated personnel. This, we believe, makes the efforts to increase the number of strong educational institutions a matter of first importance. Therefore, we urge a third type of auxiliary support: a distinct and selective program of research grants to be made available to some weaker institutions on the basis of demonstrated will to utilize new funds to raise the level of research and graduate education. The number of strong institutions must grow. We recognize that the framing of criteria by which such grants can be awarded is not an easy task, and invite careful study of the problem by a competent task force.

9. We subscribe to the conviction, expressed in the President's Science Advisory Committee 1960 report, *Scientific Progress, the Universities, and the Federal Government*, that research and the graduate education of young scientists are intimately related. Considerable progress has been made in modifying federal agency policies to adapt them to this principle since the issuance of that report. We urge continuing review of such policies in the same direction; only thus can the nation be prepared for the future.

10. In surveying the practices and regulations of the several federal agencies engaged in support of basic research, we find an extraordinary diversity. At the same time we find a growing tendency to provide the same principal investigator with multiple grants and contracts, often from different agencies, to support closely-related facets of his work.

We recognize the advantage of some variation in the practices of the several agencies, and of multiple sources of support where a principal investigator is engaged in research toward several objectives. We believe, however, that the present situation forces investigators to devote too much time to detailed accounting and other non-productive administrative matters. We urge that vigorous efforts be undertaken (a) to simplify and align the requirements of the several agencies regarding preparation of research proposals, accounting, progress reporting, and similar matters, and (b) to reduce the need for multiple support by more inter-agency agreements designating a single agency to provide total support of an investigator's work in a given scientific area.

Concerning the Universities

11. A clearer recognition by university administrations of the purpose of federal project grants and contracts for basic research is an essential requirement.

12. In dealing with federal agencies, university administrations should assert more clearly and emphatically the central purpose of American universities: the advanced education of American youth integrated with the scholarly activities of teachers; in the natural sciences these activities take primarily the form of scientific research. This purpose is not inconsistent with the purpose of the federal government in providing grants and contracts for basic research. It should be stated and restated lest both the government's purpose and the purpose of the universities be obscured by the administrative practices of the agencies.

13. University administrations, certainly no less than federal agencies, can defeat the basic purpose of federal grants or contracts for project research by their policies; for instance, by imposition of unnecessary bureaucratic controls and red tape on principal investigators, or by neglect of the investigator's problems in dealing with federal agencies. We urge a more consistent policy of positive cooperation between university administrations and the faculties engaged in research under federal sponsorship. The specific organizational forms such a policy calls for depend upon local circumstances. One form, which we believe could be widely useful, is a joint committee or board, made up of representatives of the administration, the faculty engaged in research, and supporting staff.

Some of the responsibilities that should be assumed, or acted upon more consistently, by university administrations are as follows:

(a) There should be a clear definition of the mutual responsibilities and authority of university administrations and principal investigators under grants and contracts.

(b) There should be a review of research proposals by faculty personnel to ensure only that they are not inconsistent with the concept of the university as a community of scholars engaged in both education of youth and the advancement of knowledge.

(c) There should be assistance to faculty personnel in the preparation of research proposals, to ensure that the wording of the proposals will not place undue restrictions on the scientific freedom of principal investigators.

(d) Principal investigators should be educated in the responsibilities that they assume when using federal funds in support of research.

(e) There should be an explanation to faculty personnel, primarily principal investigators, of the purposes for which overhead funds and institutional grants are being spent. Understanding of this will reduce rather widespread misunderstanding among faculties and assist in developing more harmonious relations between faculties and university administrations.

(f) Principal investigators should be relieved of as much budgetary work as possible, kept informed of the status of and commitments under grants and contracts, alerted to the possiblility of disallowance of certain expenditures, and in other ways apprised of essential fiscal requirements.

Concerning the Scientific Community

14. We believe that understanding of the purpose of the federal support of basic research by the project grant/contract system is not sufficiently widespread in the scientific community. Grants and contracts are given as trusts to institutions for a purpose, which is substantially as described by the principal investigator in his proposal. The investigator assumes a major responsibility in accepting federal funds and has an obligation to account for their proper use. Acceptance of a grant commits him to a conscientious effort to achieve its stated purpose; he acquires no other rights to the granted or contracted funds.

15. To make the project grant/contract system consistent with essential freedoms of scientific research, the substance of project proposals must be properly formulated. We have described (conclusion 4) the general form of proposals that should be acceptable to federal agencies and that should minimize that problem of overly restrictive interpretation of the purpose of a grant. We urge the scientific community to present proposals in accordance with the recommendations contained in conclusion number 4.

16. The quality and effectiveness of the project grant/contract system can be no better than the scientific community makes it, by conscientious and enlightened service on panels, study sections, and other advisory bodies and as consultants in the selection of the best research proposals. We urge the scientific community to see such service in this light and to give time willingly to it.

17. In concluding our findings, we want to remind that part of the total scientific community to which we address ourselves that they, being part of the university community, are part of a society of scholars; that they have an obligation to their society: to share in the education of youth as well as in advancing scientific knowledge.

The federal government, the universities, and the scientific community have entered into an enlightened partnership whose common purpose is the advancement of scientific knowledge and the upbringing of younger cadres to continue this task. This report is but a reminder of this central fact and an attempt to set out a few simple guidelines that should reduce some mutual irritations and help the partnership in its grand purpose of advancing the welfare of our nation and of all mankind.