After Six Years—A Study of the Impact of the Physics Branch Program[1,2]

Lawson M. McKenzie[3]

Physics Branch, Office of Naval Research, Washington, D. C.

DURING the past few months, numerous chief investigators of contracts with the Office were kind enough to give opinions regarding their association with the Physics Branch. Uniformly they lauded the program and its scientific administration. Their criticisms, always constructive, could usually be met if the principles of scientific administration behind Physics Branch policy could be fully implemented (assuming there were sufficient man-hours). It is the purpose of this document to depict the impact of the program and present a brief account of these principles in the light of comments from the contractors. Legal and fiscal issues were also discussed by the investigators. However, since these affect scientific administration only indirectly (although profoundly), they will not be discussed here.

The birth of the physical sciences as we understand them today probably occurred on February 15, 1564. This was the birthday of Galileo Galilei. In 1638, he published his monumental *Dialogues on Two New Sciences,* a treatise that covered much of his life's work. It concerned cohesion and resistance to fracture, and uniform, accelerated, and projectile motion. This served as a basis of the *Principia* published in 1687 by the famous Sir Isaac Newton, who was born the year Galileo died. Newton fully established engineering dynamics in the *Principia,* but the evanescent speculations of Galileo on cohesion and resistance to fracture have not been placed on equal footing. Today we are still wrestling with Galileo's problems, and the hope of placing cohesion and resistance to fracture on a basis as secure as that of mechanics rests in that area of atomistic physics called physics of the solid state. The laws of atomistic physics have been known for only a few decades; they required quantum theory and, particularly, the experimental findings of spectroscopy, as well as the facts that electric, magnetic, and thermal measurements provide.

One area of responsibility for the Physics Branch is solid-state physics. Grounded in atomic physics, this subject seeks to answer questions of the metallurgist, electronics engineer, and other scientists dealing with gross materials. As we see, it reaches back centuries to the work of Galileo for first notice of the problem, but only decades for work upon which to base substantial advances. Heat and cryogenics, electricity and magnetism, radiation and optics are also areas of Physics Branch responsibilities. They too depend upon modern atomistic knowledge for far-reaching advances even though their well-springs are in the works of the ancients. In essence, the central theme of the Branch is recognition of the role played by atomism in the classical divisions of the science. This then is the natural philosophical basis for the program of the Branch. We shall now examine the administrative basis of the program, although we could appeal further to the history of science for examples or go into technical details in support of this philosophy. Our purpose here is to study the impact of the Physics Branch program upon the scientific community and the administrative technique behind it. It is necessary to remember, however, that recognition of the central position of atomism in modern physics permeates all phases of Branch thinking.

As a transition from scientific to administrative philosophy, it should be parenthetically stated that the Branch considers the business of physics to be the reconstruction of facts in thought in abstract quantitative expression of the facts, where the rules which we form for these reconstructions are the laws of physics. Experimental and theoretical techniques are exploited in this process. It is exciting to examine the program in this light and cite accomplishments. Achievement, however, is the purpose of the work under contract, and hundreds of scientific papers contributed by the contractors to the technical journals cover it in detail.

Administratively, the program reflects the profound quality of physics research. It also reflects the sponsoring agency; it is a program with a Navy mission. New scientific facts, of course, are of prime importance to the highly complex and technical Naval situation. Of equal importance are the scientists behind the facts because we constantly appeal to them for special undertakings. We shall examine the program of the Branch to weigh the importance of the scientists and to determine the impact of the program upon the scientific life of the nation.

History of the support of science in the United States proves the program to be a striking development in an evolutionary process. Interplay of government, private, and semiprivate groups is involved.

[1] An article presented at the Conference on Cryogenics, General Electric Research Laboratory, The Knolls, Schenectady, N. Y., October 6–7, 1952, sponsored by the Office of Naval Research and the National Science Foundation.

[2] The views and opinions expressed herein are those of the author and not necessarily those of the Office of Naval Research or of the Department of the Navy.

[3] Executive Secretary of the Interdepartmental Committee on Scientific Research and Development.

In 1789, the first Congress authorized the Navy to conduct experiments for the improvement of ships and guns. This heedfulness to research matters is cited in the splendid study of *Applied Physics in the United States,* edited by Eugene W. Scott (*1*). Attention may also be called to the research-conscious men of our early Navy; in 1816 we note that D. Edward Cutbush, Surgeon of the Navy, became the first President of the Metropolitan Society, a scientific group in Washington. Later he aided in the establishment of the Columbian Institute, a precursor to the Smithsonian. A particular indication of this early interest in science by the Navy appears in a diary note from the *Memoirs of John Quincy Adams* (1827) in which he comments on the remarks made by Samuel L. Southard, then Secretary of the Navy, before the Columbian Institute.

> ". . . (Mr. Southard spoke) upon the obligation upon the Government of The United States to patronize science. He maintained the cause with great zeal and ability, arguing it as a duty resulting from our situation among the nations of the earth, and recurring specially to the expressed opinions of Washington, Jefferson, and Madison."

Thirty-six years later another Secretary of the Navy, Gideon Wells, appointed a permanent commission of scientific advisors to the Navy; this group later developed into the National Academy of Sciences (*2*).

History also records that in 1830 a Depot of Charts and Instruments was created; this agency was responsible for all chronometers, instruments of reflection, circles, telescopes, and charts, belonging to the Navy. It was the duty of the Depot Officer to inform himself of all improvements and discoveries in connection with navigation. A small observatory for the Depot's use was built on Capitol Hill in 1834, and in 1837 the Depot published its first nautical chart. This agency became the Naval Observatory and Hydrographical Office in 1842 (*3*). The establishment of observatories was not a result of congressional action, although it had the support of friends in Congress, typified by John Adams who "was delighted that an astronomical observatory—not perhaps so great as it should have been—had been smuggled into the number of the institutions of the country, under the mask of a small depot for charts, etc. There was not one word about it in the law" (*4*).

Abraham Flexner has admirably traced the development of the Rockefeller Foundation (1910) indirectly to the Freedman's Bureau, a post-Civil War Federal Bureau created in 1865, and to the private Peabody Fund (1867) (*5*). This pattern is indicative of early interlacing of government and private support; another such example is found in the history of the Research Corporation (1912). Frederick Gardner Cottrell wished to assign his patents to establish this magnificent grants-in-aid program to the Smithsonian Institution, but this method met with certain difficulty and the Corporation was established (*6*). The purposes and practices of the Rockefeller Foundation and the Research Corporation are well known, and their impact upon the American scene of scientific laboratory development is without equal except in extent of support. Direct government aid through the Office of Naval Research simply multiplies manyfold the available funds to carry American science to new heights in the traditional manner.

The initial task of the Physics Branch, Office of Naval Research, then Office of Research and Inventions, was contracted with the Carnegie Institute of Technology on March 1, 1946. The Task Order concerned research on plastic deformation of solids and was conducted by James S. Koehler and his students. Three other contracts, also concerned with solid-state physics research, were made that day at Carnegie Institute of Technology, Johns Hopkins University, and Cornell University. These particular tasks have terminated.

Two new tasks were subsequently initiated and directed by the two investigators at Carnegie Institute of Technology, but they are now members of the University of Illinois faculty. These tasks evidence continuity with the earlier work although, of course, they reflect the nature of the new environment. The researches formerly sponsored under the Johns Hopkins and Cornell contracts are today being continued under the sponsorship of other agencies and must, therefore, meet the program requirements of these agencies.

About one-half of the program consists of long-lived tasks; the others are shortly to be completed or supported elsewhere. Of course, immediately after World War II, the Office was virtually alone among the sponsors of basic research. A few years later, the Atomic Energy Commission began to build its program. Today, the Office of Ordnance Research, the Office of Scientific Research of the Air Force Research and Development Command, the National Science Foundation, and other agencies are sponsoring research on a project basis. With rising costs, an enlarging scientific community, and a fixed budget (the budget of the Physics Branch has remained at substantially a constant level for 5 years), such diffusion is the only mechanism to meet the new demands for necessary researches in physics. The Physics Branch welcomes these new sponsoring agencies as an aid in removing the dilemma, although the problem of multiple-sponsorship of the various programs raises new problems of scientific administration. In effect, the Branch serves the new agencies in a working capacity.

The Branch supports physics not only financially but also administratively. It is by the latter that the scientific personnel of the Branch contribute to progress of their science. A scientist in the Branch may do original research apart from his ONR duties, but his principal contribution to physics is through his function as a scientific administrator. He serves as a clearing house of scientific findings, he initiates symposia, he indicates research progress to groups in authority for the purpose of securing funds. But he is not alone; his function as an administrator is in close association with the research scientist.

This association of research scientist and scientific administrator has been of a grass-roots variety. For example, Robert J. Maurer, Chief Investigator of the Carnegie Institute of Technology contract, served as a Head of the Physics Branch. This is a particularly striking instance of the close association between the investigators under contract and the scientists of the Office. It is typical of their immediate contribution to the general program in conjunction with their equally important but far more obvious contribution through the specific research contract with the Office. It is through such relationships that the technical needs of the Navy are anticipated with vigor and effectiveness. Such factors are deemed by Branch members to contribute substantially to the strength of the program.

The contractors are not the sole source of the research scientists who have come to assist the Branch. Elliott W. Montroll, who succeeded Professor Maurer, is typical. Of course, the research scientists do not necessarily spend full time with the Office when on leave of absence from their laboratories. The Branch is fortunate in having a group of consultants who contribute to the program on a daily basis as required. Professor Maurer, for example, recently undertook a two-week study. His report is the basis for a new research and development effort that will probably be carried out at the Naval Research Laboratory by two scientists who were incidentally trained by Dr. Maurer. It should be mentioned that they received their Ph.D. degrees while working on the Carnegie Institute of Technology contract named above. Note the direct values received over and above the research contracted for at Carnegie: Maurer's direct association with ONR, and two students who obtained their Ph.D. degrees now employed at NRL.

The grass-roots basis of the program is but an indication that every effort is made to administer the program along sound lines. The administrative devices are the accepted ones in normal executive practice. It should be understood that there is nothing unique about the management of the Branch unless it is the fact that circumstances have provided a large measure of the desirable factors in its control system, and these are commonly recognized as desirable in management of any enterprise, for example, a research laboratory. These factors are nicely catalogued in an excellent book by Robert N. Anthony (*7*) and in the more theoretical and general treatment of Chester I. Barnard (*8*).

The Branch consists of Sections which are fairly stable organizational units, and they work in such concert that the program is always considered as a whole. Remembering that atomistic physics permeates the whole, the sectional division into four phenomenological areas, optics, heat, electricity, and magnetism, centers attention on areas in which the Navy's interest appears. Each topic is given essentially equal weight and organizationally these are the principal sections.

The Branch recognizes instrumentation as a science; there is also a small effort in this line to direct the fruits of novel gadgets gleaned from the program as a whole into appropriate channels. Such dividends are mainly unforeseen. This small program is the nearest the Branch comes to development although considerable foundational research is undertaken in the main areas of responsibility. By and large, the program is basic in character although the Scott document (*1*) would by definition include some of the most basic work as applied, since a Navy need exists and the work is purposefully sponsored.

To point out an example, let us consider one program which has been particularly rewarding. The subject of extremely low-temperature physics has been given principal attention in the Section on heat. Research in this area has always been considered essentially basic. Where is the Navy mission?

Properties of matter at low temperatures, when unobscured by thermal fluctuations, are important to a myriad of technical applications. A lower limit is set by nature in the case of detector elements of great sensitivity unless they are protected from sources of energy that alter their properties. Reduction of thermal fluctuation can be accomplished by cryogenic research. Control mechanisms and communications systems are obvious areas of benefit since noise reduction is the one sure means of maintaining the purity of the information being transmitted.

Extremely sensitive bolometers, the photoconductors, and crystalline electronic components are elements of Navy gear currently being engineered for low-temperature use. Superconductivity, a phenomenon peculiar to certain substances, including lead, tin, and mercury, appears only below a definitive very low temperature and at a specific magnetic-field strength. These very properties offer means to construct bolometers and magnetometers of high sensitivity and low noise. Perfect magnetic shielding is also available through the use of superconductors that thus provide means of excluding magnetic noise in the atmosphere from a space within a shield. High-Q resonators are available in the form of cavities fabricated from superconducting material. Q's of the order of millions have been reached. These are obvious areas with a Navy mission, and equally so is the insulator that becomes so perfect at low temperatures that charges are held for very long times, thus providing means of storing information. Here are uses with naval significance.

The Navy mission of basic research is generally quite obvious in the case of photoconduction, luminescence, semiconductor research, and work on para- and ferromagnetism. Military infrared, crystal rectifiers and amplifiers, and magnetic and electromagnetic gear require such research. There is scarcely an area of pure research for which a need does not exist in the formable technical enterprise that is the Navy. An even greater need exists for the trained minds and hands that are developed in the course of research carried out in our university laboratories.

The Director's Report of the American Institute of Physics (*9*) for 1951 states: ". . . it appears that 46% of physicists today are employed by educational institutions, 36% by industries, 15% by the Federal Government and the rest by nonprofit laboratories, health services, etc." Data from forty-eight Physics Branch contractors, chosen at random, give an interesting account of the distribution of their best graduates holding Ph.D. degrees. Of 549 men trained in these ONR programs, about 280 obtained the Ph.D. About half were listed as particularly outstanding, and the distribution of 198 is as follows:

Government laboratories	
Atomic Energy	18
Navy	14
BuStandards	4
Air Forces	6
	42 or 21%
Universities	66 or 33%
Industrial	
DuPont	7
Gen. Electric	16
Westinghouse	6
Aircraft indust.	9
BTL	5
RCA	4
Research instit.	9
Other	24
	80 or 40%
Foreign	10 or 6%

The importance of all these men to the Navy is clear since scientists in the industrial and academic research groups contribute almost as directly to our technical enterprise as do those in Navy laboratories.

Navy mission is one factor in considering a task for support by the Branch. The prime factor is, of course, scientific excellence. In addition to these, many factors must be considered in building the program (*10*).

1. Value of research problem
   (a) In view of overall program
   (b) Navy interest
   (c) Concentration of effort in the field
      (i) Gaps in effort
      (ii) Support of borderline fields (viz., biological)
   (d) Timeliness
      (i) Acceleration factors
   (e) Chance of striking discovery
2. Cost
3. Record of principal investigator (and associates)
4. Participation of institution
   (a) Financial or equivalent
   (b) Special facilities
5. Training of personnel
6. Stimulus to national research
   (a) Small institutions
7. Geographic distribution
8. Requested work by bureaus, Department of Defense, or other governmental agencies
9. Availability of laboratory equipment
10. Amount of money or number of tasks presently under way
11. Work load of chief investigator
12. Probability of successful completion
13. Possibility of other sources of support
14. Limit on term of project

This list does not presume to indicate order of emphasis. Although the principal criteria are necessarily the scientific value of the proposed research project, it may be of less importance when considered in connection with the other points. A few details may make the meaning clear. An important problem proposed without backing of facilities or personnel obviously lacks merit. Less obvious is the relatively important position of an adequate but minor research proposal at an institution lacking national prominence, but sponsored by a sound man with only modest facilities. The problem may be very minor indeed if a research contract is undertaken at a place where the research tradition is wanting and particularly if new research workers have to be trained.

Contrariwise, one item of considerable importance that tends to offset emphasis upon support of admittedly important work at accepted research institutions is the contribution of the contractor to the research program. It is usually a definite part of university activity to require the production of research papers by faculty members. This is a recognized faculty duty, and personal advancement is weighted by this activity. The university budgets allow for this research. The Branch seeks to accelerate and intensify such activity, but not to substitute for the university in meeting this responsibility. Participation of the institution in whatever basic work is undertaken is thus an important criterion. With respect to cost, it is perhaps selfevident that a balance between scientific value and money available must assure maximum usefulness of money spent. It is felt that the preceding list contains the most important clues to the procedures necessary for accomplishing this desired state.

Reference to the January 1952 House hearings on the National Science Foundation 1953 Appropriation Bill shows that these are the same rules of practice followed by the National Science Foundation in awarding grants-in-aid. Their list is in fact: (1) scientific merit, (2) competence, (3) institution backing, (4) budget soundness, (5) evaluation as to current research in area, (6) government interest, (7) contribution to over-all program, and (8) cost in relation to available budget.

In the hearings we read also that "while research work is neither controlled nor directed by NSF, careful administrative controls are maintained over the expenditure of all funds." Five items that are involved in the control process are: (1) payment quarterly, semiannually, or annually, (2) progress reports reviewed, (3) financial reports reviewed, (4) visits "to check the accounting for the work," (5) funds revert to NSF.

We have dwelled upon the specific deliberations of scientists within the Branch in controlling its program, and we have seen that this is also a policy of NSF. It is wise at this point, therefore, to prescribe fully the nature of this technical guidance for the purpose of avoiding any misapprehension of the role of the Branch administrator. In his association with a contractor, he is the "Scientific Officer," the responsible agent of ONR, and he is formally charged with supervision of the project. The word "supervision" is used rather than "direction," for direction often is used in a sense of "command." First of all, project supervision does not mean regulation of the course or conduct of the research contracted. It has even been suggested that the prefix "super" be eliminated to better understand the attention given by a project scientific officer to the particulars of a project. Of course, this is not a unique situation. C. E. K. Mees (*11*), in *The Path of Science,* has quoted at length the warnings of prominent directors of research with regard to the stultifying action of attempting to direct research either by a director or a supervisory board.

The principal power in the hands of the ONR scientific officer is his influence in awarding and terminating contracts. It is an important device; responsibility in using it is not light, nor is its effectiveness trivial in contributing to scientific progress. He must determine the merits of a possible project by review of proposals, by visits to laboratories, by scientific conversations with investigators, and by consultations with specialists. In terms of a research program and status of the budget, he must then determine whether or not to recommend the award of a contract. After a contract has been in force, he must use the same means, together with vision of the probable outcome of the investigation, to determine whether to extend or terminate the contract. These actions, of course, are taken in accordance with the general doctrine of the Office of Naval Research.

It must be re-emphasized that the Branch scientific officer is principally a scientist, although in most cases he is not a specialist in the same sense as the investigator whose work is under his cognizance. But by his breadth of experience, this officer serves as a valuable link between extreme specialties. He plays an unusual role, therefore, in the scene of scientific communication. The contractors have themselves expressed a need for such information. This is a very active part indeed in the particular research program he supervises.

One function of his office is to create a tie between projects, thus bringing them together into a well-organized program. It is by no means an invisible tie. He has a power to call conferences of the contractor's representatives and thus create small, intensive, ad hoc scientific societies for the mutual benefit of the investigations under way. This serves to avoid duplication and to swiftly pass along advances as they are made. It also serves to inform scientists of naval problems and weds the program, not only by fusion to itself but also by diffusion, to the broader program of the ONR, the Navy, and Defense Research. The conferences called by the Branch have the enthusiastic support of the contractors.

He controls details of the budget of the project. Travel authorization is one important example. As Bernal (*12*) has said, "It is a common experience in visiting laboratories to notice at the same time unsuspected improvements which have been in use for years and obsolete techniques which have survived for as long a period. To carry on with obsolete methods may often lead to the waste of years of effort, but this waste is inevitable unless much more rapid and direct personal means of communication between scientific workers is effectively organized." The power of travel authorization in the hands of the project supervisor is thus a major device with which he may enhance the efficiency of a program. He must use it wisely for its abuse may jeopardize his control of it.

Still another consideration is the approval of expenditures for items costing more than a certain sum. One of several theories for support of basic research does not allow purchase of capital equipment, but does require the money to be spent on scientific personnel (i.e., brains). Thus, approvals of large expenditures on equipment abridge this rule. Indeed, examples can be cited to show the appropriateness for authorizing such expenditures and the consequent benefits to the progress of the program. Such are the paradoxes that daily must be resolved by the scientific administrator.

Mees (*11*) remarked, "The administrators and organizers of society have been trained chiefly in the humanities and are largely ignorant not only of the facts of science but of the scientific method. The scientists, on the other hand, are absorbed in their own problems and too often have little time to spare for (the humanities). . . . The humanists must understand what the scientists have done in the past, are doing now, and may do in the future; while the scientists must see their work in the light of history and in relation to the effects that its application to social conditions will produce."

The scientific officer effects this necessary liaison between research and purely administrative functions. He must satisfy the fiscal officer's wariness of "boondoggling" in the latter's ultimate accounting procedures by demonstrating to him that true value can be obtained through authorization of unusual expenditures, for example, the rule of government publication policy. Such matters are often puzzling concepts to scientists unaware of government policies and the way in which the government works. It is the role of the scientific administrator to bridge this gap.

C. I. Barnard (*8, 13*), the president of the Rockefeller Foundation, indicates that intuition plays a primary role in the successful function of the executive. One frequently hears science program administrators say that they must "play by ear" to arrive at decisions. This is but another way of stressing the fact that intuition must be highly developed in this class of scientific personnel. Intuition development is not a mysterious process; it certainly is not second sight. It represents the sum of the experiences of the scientist and, when he acts as an administrator, his experiences from an interaction with many segments of society. The success of a scientific officer does not rest upon his meritorious performance as a research scientist alone—he also must have either the necessary humanistic background or genuine desire to put aside full-time research long enough to cultivate it.

The Physics Branch scientific administrators and their advisors and committees strive to build not only a strong program of basic physics, but also to apply the basic program to its Navy mission. The present program in basic research has resulted from years of work by the Branch, and it is the reservoir that is feeding an applied program administered by the Branch and sponsored broadly throughout ONR and the Navy.

It is obvious that the program depends upon the scientist acting as an administrator; as a corollary, this is a requirement for a grass-roots program. The business administrator is unfit for this role. Yet in the excellent book of Anthony (*7*) we find this point misunderstood. We should not go to the opposite extreme, for the business executive certainly has a role that is recognized by the Branch scientific administrator as vital to the program.

Anthony states, "The research worker typically does not understand or care much about the problems which confront the management of a laboratory. In general, he believes that these problems are less important than the specific technical problems on which he is working, although out of politeness he frequently will not say so. In the course of our investigation, we hear administrators and administrative functions described in terms which cannot be printed here" (*14*). Anthony also declared, "Formal communication (i.e., paper work) is generally disliked by everyone, and especially by technical personnel" (*15*). However, it is difficult to determine his meaning unless it is to influence the reader who is also urged to doubt the validity of the opinion that "Scientists and engineers are almost unanimously of the opinion that the head of a research organization must be technically trained and technically competent" (*16*).

The role of the scientific administrator finds its complete expression in the administrative controls of ONR. To repeat, this is recognized by the Physics Branch as the essence of its program. It is hoped that this exposition will help those interested to appreciate the function of the scientist in the Physics Branch program of atomistic physics research. The methods of administration have been lauded in many letters from contractors to the Branch. They uniformly express the opinion that this is a most important feature of the program to them.

Although this analysis is specific to the administration of the program of the Physics Branch, it is perhaps not too presumptuous to speculate that the same analysis may be directed more generally. In the Sixth Annual Arthur Dehon Little Memorial Lecture at MIT, Sir Henry Tizard (*17*) casts the role of the scientific administrator in the broad role of service in our free democratic society. He stated: "I hold that if science is to have a real influence on national policy, some scientists must be prepared to spend part of their lives in the closest daily touch with men who formulate the policy. It is not necessary that they should be the best scientists, so long as they enjoy a reasonable measure of the confidence of more gifted colleagues, and do not retreat too far from the advancing tide of science."

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