Opportunities in physics and major research facilities

How can we set priorities in physics research and at the same time achieve a balanced approach?

L. Charles Hebel

Few human endeavors have been as fruitful—intellectually, technologically and culturally—as the study of physics. Recent discoveries and future prospects are the subjects of two current evaluations. The *1984 Research Briefing on Selected Opportunities in Physics* (PHYSICS TODAY, January, page 20) has been prepared by a panel headed by Hans Frauenfelder and Mildred Dresselhaus for the Office of Science and Technology Policy and the National Science Foundation. Also, the Physics Survey Committee, headed by William Brinkman, is completing its report for the National Research Council. As observed in the *1984 Research Briefing*:

> Progress in physics over the past decade has been remarkable. Puzzles that seemed to present insuperable challenges at the beginning of the 1970s have yielded to powerful and elegant theoretical and experimental techniques. New insights and accomplishments have not only brought greater unity to the various branches of physics but have also strengthened the ties of physics to other areas of science and opened a vast array of new opportunities. Every part of physics has participated in the advance....

The *Briefing* highlights six subfields of physics with research opportunities across a broad intellectual frontier and with bright prospects for advances.

▶ Laser-atomic physics—such as new spectroscopies, trapped particles, creation of new species, matter in intense fields, new light sources

▶ Relativistic plasma waves—such as new particle accelerators, generation of electromagnetic radiation

▶ Deliberately structured materials—such as surfaces and interfaces, thin films, layered structures and superlattices, disordered materials

▶ Biomolecular dynamics and intercellular cooperativity—such as biomolecular dynamics, molecular basis of information storage, transmembrane signaling, intercellular cooperative processes

▶ Cosmology—such as the origin and evolution of the universe, elementary-particle physics

▶ Nuclear matter under extreme conditions—such as quark–gluon plasma, interior of neutron stars.

Major physics-research facilities

In some physics subfields, fundamental advances typically are made in the laboratories of individuals and small groups who work in the traditional university research mold. But in several physics subfields, vigorous frontier research depends critically on major and increasingly expensive research facilities, as the articles in this edition of PHYSICS TODAY amply demonstrate. Large accelerators are crucial to advances in elementary-particle and nuclear physics. The Superconducting Super Collider is a dramatic proposal for the next major facility for elementary-particle research, and various heavy-ion colliders are on the drawing boards for nuclear research. For the study of condensed matter, from biological materials to electronic device structures, major neutron and synchrotron light sources are powerful research tools. Major research facilities also are essential to a broad fusion research effort together with a variety of smaller-scale experiments.

Indeed, progress in several physics subfields would fade without major research facilities. Sharing them has become the norm for a sizable number of physicists, despite personal inconvenience and stress on individuals and groups. For years many physicists have been concerned about major facilities, particularly their effect on the university research and teaching environment. Two factors have caused these latent concerns to surface now:

▶ Ever-larger price tags for forefront physics research facilities, some costing from hundreds of millions up to a few billions of dollars. While the SSC stands out in cost, other major facilities raise similar issues.

▶ The huge, unresolved imbalance in the Federal budget, which is finally commanding attention from the Administration and Congress.

Some physicists assert that major facilities are not only essential for vigorous research but also healthy for physics budgets; by funding them, "all boats will rise." Others regard this view as optimistic; they fear that something closer to a "zero sum game" may be in store for physics as the government deals with the huge Federal budget imbalance. In addition, research increasingly is subject to pressures for the US to become more competitive economically. Thus, while physicists recognize the essential role of major research facilities, many are worried that budgetary forces may harm their own research field as well as physics as a whole. Their concerns involve three main issues: justifying facilities, setting priorities, and achieving and maintaining balance.

Justifying facilities, setting priorities

Justification of a new physics research facility requires a twofold evaluation, namely, its scientific merit (objectives, rationale and technical approach) and its consequent technological benefits to society. Physicists usually excel at assessing the prospects

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for scientific advance and research excellence. Their record is less outstanding in forecasting the technological consequences. Historically, fundamental research can spawn major technological benefits and even create whole new industries. Sometimes such benefits are anticipated at the beginning of a research project, but often they are foreseen only in general terms, if at all. In fields that involve close ties between science and high-technology industry, the induction time between scientific advances and economic impact is growing shorter. However, not all research projects have equal technological promise, either by design or by serendipity; in fact, the technological impact per dollar invested varies widely. Thus, in today's climate of rising research costs and tight budgets, proponents of any major facility must be especially forthright in sharing their vision of the research opportunity.

Even with carefully justified research proposals, setting priorities is not straightforward. There is no calculus of costs versus benefits for projects that are basically scientific. Agencies must make funding decisions on more qualitative grounds, focusing on the scientific merit of the proposal but considering technological benefits where they can be identified. With some notable recent exceptions, agencies and Congressional committees seek guidance from scientists about research priorities, project rankings and allocations for facilities. Several of these exceptions disregard legitimate priorities and processes of the scientific community and base the funding decisions on other, more expedient grounds; such a pork-barrel approach diminishes science. But a few of these exceptions may be a response by the Congress to aspirations of some scientists and institutions that have failed to get a hearing within the scientific community's established processes; such instances challenge the community to reexamine its processes.

Specialists within physics subfields depend on the time-honored methods of peer evaluation to rank proposals and even to set relative priorities. In some subfields, peer review is centralized in a committee that reports its findings at a high level in the agency that funds the research of that subfield: for example, the High Energy Physics Advisory Panel, the Magnetic Fusion Advisory Committee and the Nuclear Science Advisory Committee. Peer review is more decentralized in several other subfields, especially those where small-group research predominates: for example, condensed-matter physics, biophysics, atomic and molecular physics. A decentralized approach to peer review seems to fit the folkways of these subfields. But lack of a mechanism that is representative of a whole subfield may hinder it from speaking with a unified voice on funding and policy matters.

Across physics subfields or among major categories of the science budget, priority-setting is much less clear cut. The National Science Board and a collection of high-level advisers, who operate largely out of view of the technical public, provide guidance to decision makers. At this level, science policy is reconciled with defense and economic policies to reflect national interests. Industrial policy also has a strong influence on science policy and priorities, especially as the government seeks to improve the competitive posture of the US. Thus the physics community must give sound justification for facilities and clearly state its priorities within physics subfields. But issues outside of science strongly affect funding decisions.

Achieving balance

A balanced approach to physics as a whole is a matter that concerns the entire physics community. All physicists endorse research to advance the scientific frontiers, and all share a respect for the unity of physics. They draw special satisfaction from the important and largely unanticipated contributions—theoretical, experimental and technological—that demonstrate this unity through progress in different subfields. A classic example is the concept of symmetry-breaking, which has strongly influenced both condensed-matter and elementary-particle physics. Another example is the discovery of high-field superconductivity, which has led to greatly improved magnets for accelerators. Conversely, accelerator development has led to synchrotron light sources that are important in condensed-matter physics and biophysics.

Balance involves a coherent selection of the best prospects for fundamental advances in the subfields, prospects that wax and wane with time. Thus, at a given time, balance does not require that all subfields receive equal emphasis. The research fields and topics in the *1984 Research Briefing*, listed above, illustrate a well-balanced choice of current opportunities with high scientific potential and varying time scales for perceived technological spin-off. A correspondingly balanced funding approach would feature a spectrum of high-quality research efforts of varying size and scale, from programs of individual physicists to group endeavors that center around major facilities. For several decades the physics community in the US has been reasonably satisfied overall with the internal balance in physics research. The challenge is to achieve it in the face of rising facility costs and a national budget hiatus.

Many physicists are troubled about the distortion and imbalance that could result if major research facilities were funded without due regard for the essential contribution of numerous smaller but high-quality research programs. The majority of physicists are engaged in individual and small-group research programs and have no single facility to bring them together scientifically or politically in common cause. Such programs not only make many fundamental scientific and technological advances in their own right, their efforts often prove crucial to the interpretation of results obtained with major facilities. Moreover, small-scale programs form the backbone of the traditional university environment that provides the future lifeblood of physics.

Likewise, a small percentage budget overrun for a major facility could have a devastating impact if funds to cover the overrun were drawn from the same budget category (or organization) as smaller research projects. By and large, the track record with physics research facilities has been good. But as costs for major research facilities become a greater fraction of the science budget, their financial impact is more likely to reach beyond the confines of a particular subfield. Thus the physics community is confronted with a predicament. Physicists generally endorse forefront research that requires major facilities; yet many are concerned about the possibility that funding a major research facility for one subfield might limit or even reduce research funds for other subfields. A balanced approach to funding—one that emphasizes the best research opportunities at a given time and high-quality efforts of various sizes—is a basic policy issue for the entire scientific and technical community.

Currently, we must deal with this issue in the absence of a mechanism that is representative of the entire community. Physicists must speak their minds as individuals and members of committees and groups. Their voices can be more effective if they learn about issues and opportunities outside their immediate research field. Physics, physicists and the public will be best served by reasoned, accurate, and responsible discussion among subdisciplines. The editorial (page 184) focuses on how the physics societies can facilitate more cross-disciplinary discussion and information exchange.

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