Physics in Perspective: A New Report

As late as the mid-1960's, physics was a growth business in a robust state of health. Since then, federal support of science has leveled off, industrial research efforts have been cut in the face of declining profits, and university positions for scientists are in short supply. For physics, the experience has been something of a shock. The discipline found itself heavily dependent on federal money from military and space programs that were being reduced, its practitioners largely out of step with the needs of industry, and its university departments often devoted to producing narrowly specialized young scientists. The physics community and its organizations have been forced to confront a host of unwelcome problems. Now, 6 years after the last exercise in self-examination and prognostication, physics is again the subject of a National Academy of Sciences report on the status of the field and the prospects for its future.

Physics in Perspective is the title of the massive, 1000-page report of the Physics Survey Committee, of which D. Alan Bromley of Yale University is chairman (*1*). The report, which emanated from a 2-year study conducted under the auspices of the academy's Committee on Science and Public Policy (COSPUP), breaks new ground by attempting to deal with the sticky question of priorities for research in physics. Unlike earlier reports, it avoids claiming any specific fraction of the nation's resources as physics' due. And it does not mince words in recommending what are certain to be controversial new policies for university departments and funding agencies alike. But even with this display of courage, the report does not cleanly settle many of the issues it addresses. Despite touches of excellence, the report is flawed by its unmanageable length and its credibility is diminished by warnings of disaster should American physics lose its international preeminence.

The survey committee found that physics is still a thriving and extremely productive branch of science, indeed so much so as to have surpassed most prior expectations. Scarce resources are beginning to hurt, however, and the fundamental problem confronted by the committee was what to do when there isn't enough money to go around. After considerable debate, they chose to recommend that scarce resources should be concentrated on "the support of excellence" at major facilities and at the best universities, rather than be broadly distributed. The report is thus unabashedly elitist. Indeed, according to Harvey Brooks of Harvard University—who as past chairman of COSPUP had a major hand in shaping the report—physics is inherently an elitist profession.

Specifically, the report recommends that some programs should be terminated and facilities closed rather than operate all programs under marginal conditions, that new facilities should be restricted and should not be approved for reasons of geographical or institutional equity, and that physics departments should concentrate on their strengths instead of attempting to provide programs in all areas of physics. But the recommendations, which run contrary to the major thrust of federal support of higher education in recent years, seem certain to draw criticism from universities with ambitions for upgrading their physics departments and from small research groups which fear that they will be squeezed out in favor of larger groups. The recommendations also have the effect of encouraging "big science" to get bigger, but do not resolve the question of whether large well-funded research groups are intrinsically more productive of research than small groups.

To help funding agencies decide where to spend their money, the survey committee developed an elaborate set of criteria for assessing the relative scientific merit, and their potential for socially useful applications, of 69 different specialties within physics. The 15-member committee, composed of senior physicists from many of these specialties, surprisingly reached consensus concerning the priority areas for research. Elementary particle physics accounted for five of the top ten choices on the list of 69 when ranked according to criteria that reflect only scientific considerations. When only considerations external to science were included, specialties in nuclear physics, plasmas and fluids, condensed matter, and optics dominated the top of the list. Research on lasers was high on both lists. The report cautions that priorities may change rapidly, and that its ratings represent only the opinions of the committee; but it goes on to suggest that funding agencies and others concerned could use the same criteria to develop their own lists of priorities.

Having provided several lists of priorities within physics, the committee and its subpanels used these priorities in assessing, separately for each subfield, how a given amount of funds should be distributed. The study did not include the more difficult question of how funds should be distributed among the subfields, except to indicate a consensus that the present distribution of money was about right (see Table 1). Fifteen areas of research, however, were picked out as worthy of special priority in the next 5 years (see box).

The committee and its subpanels examined the consequences of four different budgets for physics research—growth at 11 percent per year, growth at 6 percent, no growth, and a 6 percent annual decline. The details of who would get what under each of these situations—details that are likely to be of considerable interest to the researchers benefiting—are to be found in the various subpanels' reports, which will be published as a separate volume later this year. While not recommending a particular budget, the report does devote a chapter to making the case that many worthwhile scientific and practical endeavors will have to be forgone unless more money for physics is provided by the federal government—which most observers do not expect to happen. And declining budgets, the report maintains, would lead to serious and lasting damage to many subfields of physics within 5 years. The report recommends that both the traditional science agencies and those more oriented to social problems should increase their support of physics, and that some of the money should be granted on a long-range basis to prevent year-to-year fluctuations in the research effort.

While some of the warnings of dire consequences for lack of money are less than convincing, there is no question that the squeeze is particularly tight in elementary particle physics and nuclear physics because of the cost of commissioning large new accelerators. Both the National Accelerator Laboratory at Batavia, Illinois, and the Los Alamos meson facility in New Mexico are scheduled to begin full operation next year, and the advent of these facilities will hasten the trend to "big science" and large user-groups at the expense, if no other money can be found, of smaller research groups and older accelerators. Cooperative arrangements for using large accelerators and telescopes are becoming an increasingly necessary way of life in elementary particle physics, nuclear physics, and astrophysics; and the high costs for equipment make research in these fields relatively more expensive (see Table 2). Other subfields of physics, even though they involve larger numbers of investigators, have more flexibility to adjust to different amounts of funding.

Despite the essentially stagnant budgets that physics and other sciences have endured for about 5 years, the report finds that progress in research has been very rapid—even more rapid than envisioned in an earlier report. The survey committee even noted some salutory effects of the funding freeze, such as more efficient use of resources and realignment of priorities and attitudes within the physics community. One genuine difficulty, however, is the shortage of jobs for physicists—although the extent to which this is the result of a lack of money or of earlier manpower policies is problematical.

The Future of Physics

Fifteen areas of research in physics are highlighted by the Bromley report as "high leverage situations" whose potential for results of scientific or societal importance is great enough to warrant high priority for the next 5 years. As such, the list is a kind of forecast as to where the action will be in physics in the near future. The following descriptions of these research areas, which appear in an arbitrary order, are adapted from the report.

Macroscopic quantum phenomena. This area includes superfluidity and superconductivity, and is an example of a fundamental problem in physics, that of many-body systems. Potential applications of these phenomena include superconducting transmission lines for electricity, transportation with the use of magnetic levitation, and compact high-efficiency motors.

Heavy-ion interactions. The interactions of large pieces of nuclear matter makes accessible new modes of nuclear motion. The field also makes accessible new nuclear species—both unknown isotopes and possibly new transuranic elements. There are potential applications in medicine, in power generation, and in national defense.

Higher energy nuclear physics. New facilities, typified by the Los Alamos meson facility and by the Brookhaven synchrotron, will make possible the extrapolation of studies of the behavior of the fundamental nucleon–nucleon interaction at very short distances.

National Accelerator Laboratory. As the world's most powerful proton accelerator, this facility holds high promise of discovering fundamental new aspects of nature. It represents a frontier in man's understanding of the ultimate structure of matter.

Stanford Linear Accelerator. This facility is the world's most powerful electromagnetic probe for the study of the structure of matter. It is complementary to the National Accelerator Laboratory.

Controlled fusion. The field holds high promise for the development of a new power source with a reduction in deleterious side effects.

Lasers and masers. Applications of these devices have been pervasive throughout much of science and technology—and in medicine and the fine arts. The exploitation of these new devices has only begun.

Quantum optics. This area is closely related to that of lasers and masers and shares similar advantages and potentials. In addition to investigations of the basic structure of both solids and liquids, the field holds high promise of very important new applications in miniaturized devices, wide-band communications, and high-speed computers.

Nonlinear optics. This area can provide an interface between atomic and molecular physics, condensed-matter physics, and major areas of technology. Work in this field and in quantum optics and laser phenomena are to a great extent symbiotic, with major progress in one opening up opportunities in the others.

Atomic and molecular beam studies. Atomic or chemical accelerators that have recently become available can provide beams of atomic and molecular species at the energies suitable for application to atomic physics, chemistry, and biology. This makes possible the transfer of many techniques from nuclear and particle physics, and puts the understanding of chemical reaction mechanisms on a new and more fundamental basis, and provides insights into basic mechanisms in molecular biology.

Scattering studies on solids and liquids. These studies involve scattering neutrons, photons, and phonons in liquids and solids. New techniques and more intense sources have enabled rapid progress in understanding the microscopic order in condensed matter.

Turbulence. This is an area of extreme complexity, but one of correspondingly great importance in all areas involving fluid flow. Turbulence phenomena occur in aeronautical and shock-tube phenomena, in meteorology and oceanography, and in the flow of blood in human circulatory systems.

Biophysical acoustics. Recent progress in this field has provided a new understanding of the physics involved in speech and hearing. It holds high promise of alleviating a wide variety of incapacitating human ills within a relatively short time.

Very large radio array. Provision of a very large radio telescope holds high promise of major new discoveries about the structure of the universe.

X-ray and gamma-ray astronomy. A high-energy astronomical observatory may make possible increased fundamental insight into the structure and history of the universe.

The report devotes considerable attention to manpower supply and demand in physics. The committee had access to new sources of data, and their discussion is heavily documented. What emerges is a confluence of demographic and economic factors that add up to a dismal outlook for young Ph.D.'s. Even the committee's most optimistic projections show a serious oversupply for the next 5 years at least. In that period, the report projects 7000 new Ph.D.'s, but less than 4700 new job opportunities.

The report admits that much of the decreasing academic job market for scientists should have been evident beforehand, thereby accepting for the physics community some of the blame for the mess; this appears to be an improvement in the attitude that characterized the response of much of the physics establishment to manpower issues until recently. The committee recommends specific measures to ease the difficulty of new Ph.D.'s—the replacement of graduate students in undergraduate teaching with postdoctoral physicists, reduction in the size of entering graduate classes, and the active solicitation of jobs in areas of employment outside research and development. The report thus gives an establishment blessing to measures that, in many cases, were first suggested by dissident groups of graduate students.

But if the report displays concern for the victims of past policies and deals more responsibly with projections for the future than did its predecessors, it still reveals the attitude that physicists are good for the country and indeed can replace other scientists in many jobs. The report not only disagrees with projections by Allan Cartter of New York University (*2*) and others that foresee an almost indefinite oversupply of physicists, but even ventures to suggest that increased employment of physics in industry and, more vaguely, in areas outside research, could lead to a new shortage of physicists by the end of the decade—provided that the federal government responds enthusiastically to the suggestions contained in the report.

The assessment of U.S. physics undertaken by the Bromley committee is of unparalleled scope, and contributes to the bulkiness and lack of focus in the report. There are chapters on physics and U.S. society, on the international aspects of physics, on the institutions of physics, and on the agencies and federal policies that govern funding for physics research. Some 57 recommendations are addressed to federal policy-makers and to the academic community. A virtual textbook on recent developments in each of the subfields of physics—directed to the prospective graduate student trying to choose a field or to the nonphysicists—provides some of the best reading in the report. In this effort, the authors of the report also include material on interdisciplinary fields, such as physics in biology, physics in chemistry, geophysics, and instrumentation. A glowingly written chapter of the nature of physics deals with the unity of science and the relation of physics to other sciences and to technology. Another chapter discusses the dissemination and use of information in physics, concluding that, although more and better review articles are needed, the archival journal articles are still the basis of printed communication.

Table 1. Operating costs for U.S. physics in fiscal 1970.

Subfield	Cost (10^6)		
	Federal	Industrial	Total
Acoustics	14	1	15
Astrophysics and relativity	60	0	60
Atomic, molecular, and electron	13	7	20
Condensed matter	56	80	136
Nuclear	73	2	75
Elementary particle	150	0	150
Plasma and fluids	77	10	87
Optics	12	7	19

In a section on physics and education, the report recommends that both graduate and undergraduate curricula be broader and less specialized, in part to restore the traditional flexibility of the physicist. At the major universities, the report suggests, "the best possible" physics education should continue to be the goal, but training for jobs in industry and other practical aspects of physics should receive more emphasis in all physics departments. Most of the leading universities have already decreased their graduate enrollments, but the report notes that total enrollments in physics have not decreased, implying that the students have simply gone to less prestigious schools; it recommends that the best departments should run at full capacity, while others reduce their graduate enrollments.

Table 2. Approximate costs per Ph.D. man-year in experimental physics. Costs are for operations and equipment and do not include the amortization of major facilities. When space-based research is included in astrophysics and relativity, the cost is about $200,000. The report estimates that theoretical physics costs about $35,000 per Ph.D. per year.

Subfield	Cost (10^3)
Acoustics	55
Atomic, molecular, and electron	50
Condensed matter	70
Elementary particle	175
Plasma and fluids (not including fusion)	60
Controlled fusion	150
Astrophysics and relativity	55

The report expresses alarm at the low degree of public understanding of science, and proposes that physicists who can contribute to improving the situation should be encouraged to do so. Specifically, a fund to be raised by assessing members of physics societies is proposed to underwrite a series of television programs and other mass media ventures aimed at improving the public understanding of physics.

The report appears to be a genuine effort to come to grips with both the far-flung nature of the physics enterprise and the real problems confronting it. To the extent that the report is influential, its priorities will be highly unpopular with the losers in the battle for funds. Some critics have charged that representation on the survey committee, and in particular on the nuclear physics subpanel, was unintentionally biased toward the agency-controlled national laboratories—in effect, that the participants were predisposed toward "big science," with the result that policy issues were insufficiently debated. Whatever the truth of these charges, the report does not claim to represent any more than the views of its authors.

The report is not likely to succeed in convincing the government to put its science policy on a more rational basis, although the detailed criteria and the rating processes that the committee developed may find some use in the federal agencies. The physics community itself, however, could implement many of the report's suggestions for broadening the training and opportunities of physicists. Indeed, physicists and other scientists may be in the best position both to appreciate and to take advantage of this new perspective on physics.

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References

1. D. A. Bromley, Ed., *Physics in Perspective* (National Academy of Sciences, Washington, D.C., 15 August 1972), $25.
2. A. M. Cartter, *Science* **172**, 132 (1971).