PHYSICS THROUGH THE 1990s

Scientific Interfaces and Technological Applications

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Panel on Scientific Interfaces and Technological Applications

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Preface

Physics traditionally serves mankind through its fundamental discoveries, which enrich our understanding of nature and the cosmos. While the basic driving force for physics research is intellectual curiosity and the search for understanding, the nation's support for physics is also motivated by strategic national goals, by the pride of world scientific leadership, by societal impact through symbiosis with other natural sciences, and through the stimulus of advanced technology provided by applications of physics.

This Physics Survey volume looks outward from physics to report its profound impact on society and the economy through interactions at the interfaces with other natural sciences and through applications of physics to technology, medicine, and national defense. Six other volumes recount the status, progress, and promise of physics as scientific enterprise in the major physics subfields of particle physics; nuclear physics; plasma physics and fluids; condensed-matter physics; atomic, molecular, and optical physics; and cosmology, gravitation, and cosmic-ray physics. An overview volume addresses the overall progress, opportunities, and needs of the field; analyzes the status and trends of U.S. physics on the world scene; and discusses funding, manpower, and demographic issues.

The vital role of physics in propelling the entire scientific enterprise and in providing the basis for new technologies of immense economic importance is evident throughout this Survey, but it is the present volume that focuses on technological applicability.

New scientific disciplines are arising from the scientific interfaces between physics and biology, geology, and materials science. The traditional interfaces with chemistry and mathematics are acquiring new connections that promise revolutions in the way that research is conducted. These scientific interfaces are explored in 6 chapters that illustrate selected examples of the progress and trends that appear in appropriate symbiotic relationships. The emerging impression is a scientific whole that greatly exceeds the sum of its parts. Interdisciplinary science at the most fundamental research level is shown to be one of the most exciting promises for the coming decade.

The interfaces between physics and the various engineering disciplines are not treated explicitly. But the crucial continuum of physics activity from the most basic research to engineering applications is emphasized. Its reality must be recognized, supported, and strengthened for the national good. Indeed, more people trained in physics are engaged in applications or engineering than in pure research or academic pursuits.

Microelectronics, optical communications, and new instrumentation exemplify the major technological applications of contemporary physics research. A diversity of physics applications contributes to advances in medical diagnosis and treatment, to national defense systems, and to solutions of energy and environmental problems. Six chapters of this volume discuss these important areas of application of physics, largely in terms of their societal and economic impact.

Consideration of the interfaces and applications of physics leads naturally to recommendations aimed at strengthening the vital continuum joining science, technology, and our national prosperity. They are specified and explained at the conclusion of Chapter 1, Summary and Recommendations.

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Executive Summary

Physics research combines a drive for understanding of the natural universe with a pervasive influence on the quality of human life through the technology that it generates. The exhilarating twentieth-century pace of discovery and application has accelerated in the past decade. New technologies, such as high-speed electronics, optical communication, advanced medical instrumentation, exotic defense systems, and energy and environmental systems, have nucleated and grown to maturity within only a few years after the physical discoveries on which they are based. At the same time, new ideas and methods born at the scientific interfaces are evolving scientific capability to address ever more complex problems. Physics has both contributed to and drawn from the sciences of chemistry, biology, and mathematics in entirely new ways. Computer science, geology, engineering, and materials science have become fully symbiotic with physics, to the benefit of humankind.

This volume illustrates these advances through representative examples and recommends actions to enhance the value of physics to society through both its scientific interfaces and its technological applications. Recognizing the importance and complexity of the science-technology-economy continuum, it seeks to strengthen these interconnections in key areas.

In addition to general recommendations put forth in the Overview volume of the Physics Survey, we propose the following:

- Funding agencies should devise procedures to evaluate and support interdisciplinary research collaborations involving participants from deep within the associated disciplines. Special attention should be given to start-up research grants for young faculty to begin interdisciplinary programs.
- The universities should promulgate interdepartmental, interdisciplinary research programs and centers to transcend barriers among the traditional disciplines, to provide transdisciplinary education, and to attract and utilize interdisciplinary research funding.
- Universities and funding agencies should organize to accommodate and enhance the engineering-physics interface in both education and research.
- The federal government should encourage in-house industrial fundamental research and cooperative industrial research with universities, national laboratories, and other industry through appropriate tax and antitrust policies.
- The support of long-range fundamental research should be shared by the mission-oriented agencies, particularly the U.S. Department of Defense, and be restored to at least pre-Mansfield Amendment (1970) levels.

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Summary and Recommendations

PERSPECTIVES FOR SOCIETY: APPLICATIONS, IMPLICATIONS, AND INTERFACES OF PHYSICS

Research in physics increases our fundamental understanding of nature, generating knowledge with far-reaching consequences for humankind. The new technology that it has spawned is so ingrained in our civilization that its scientific origins are often overlooked. This volume of *Physics Through the 1990s* reports on the profound societal impact of physics through its applications in technology and its interfaces with other sciences.

As a fundamental science, physics presents some of the deepest challenges ever to engage the human mind. The excitement of discovery in physics has accelerated its pace throughout this century. The other volumes of this survey detail these discoveries in the subfields of elementary particles; plasmas and fluids; nuclear as well as atomic, molecular, and optical physics; condensed matter; and cosmology and gravitation.

Unlike the sometimes altruistic patronage of the arts by medieval authorities, the substantial level of contemporary federal support of physics research is motivated by the anticipation of practical benefits. Yet despite media accounts of spectacular discoveries in such areas as elementary-particle physics, interplanetary science, nuclear fusion, and exotic superconductors, scientific research often seems to remain disconnected in the public mind from practical concerns of the U.S. economy. This volume demonstrates the value of physics to society and conveys a sense of the importance to the economic health of the United States of its world leadership in both fundamental research and technological innovation.

From the breadth of physical activities that compose the applications of or scientific interfaces with physics, this volume reports on several fields of current excitement and future potential, as well as several fields of immediate importance to society. The selected interfaces represent those in which interdisciplinary interaction is particularly vigorous at fundamental levels: biophysics, materials science, the chemistry-physics interface, geophysics, and mathematical and computational physics.

From among the innumerable applications of physics, we have selected several areas that combine pivotal dependence on recent research with an identifiable large-scale industrial technology. We highlight applications of physics in electronics, in optical information technologies, in new instrumentation for both science and society, in the fields of energy and environment, in national security, and in medicine.

In many of these applications the lines between physics and engineering are frequently and necessarily crossed. Although engineering is not treated explicitly within this volume, its crucial role permeates essentially every aspect of the technologies represented here. Continued technological progress depends on intense interaction between physics and engineering just as continued scientific progress depends on interactions between physics and other sciences. Indeed, the continuum of viewpoints shared by science, technology, and engineering is a major underlying theme of this volume.

In each of the chapters the major advances of the past decade are surveyed within the framework of physics research, focusing on representative examples rather than exhaustive compilations. Specific recommendations of a particular technology or scientific interface appear in the appropriate chapters. Recommendations that transcend individual specialties and suggest programs by which society and science may continue to benefit from progress in physics are drawn together in the final section of this chapter.

SCIENTIFIC SYNERGY: THE SCIENTIFIC INTERFACES OF PHYSICS

Because the principles of physics serve as a foundation for other sciences, new discoveries in physics frequently stimulate research in associated sciences. In turn, problems of other sciences can present physicists with profound challenges.

Each of the 6 interfaces presented here illustrates different implications of physics, presents its own opportunities, and leads to particular conclusions and recommendations.

Although the interfaces of physics with the various engineering disciplines have not been addressed here explicitly, we note emphatically that there exists in physics a continuum of technical activities without any sharp distinctions from the most fundamental scientific research to the most immediate technological applications. Thus, in those areas of technology where new physical science is moving rapidly into application, there is no point in attempting to distinguish between physics and engineering.

Biological Physics

The elegant complexity of life often diverts our attention from its ultimate reliance on the principles of physics. The tools of physics have always been involved in biological research, and the fundamentals of biological phenomena have increasingly challenged physicists. Early optical microscope observations of bacterial motion (Brownian motion) led Albert Einstein to formulate the basic statistical mechanics of fluid diffusion, and it was modern electron microscopy that identified the structure of molecular photodetectors packed in a two-dimensional lattice of cell membrane.

Biophysics is, however, more than the application of physical methods to biological systems. Fundamental biological challenges stimulate new applications of concepts of theoretical physics. Today, for example, the *biopolymers*—the proteins and genetic materials DNA and RNA—have a well-established empirical chemistry thanks to continuously improving physical experiments. Fundamental understanding of protein structure and function now appears to be a realistic research objective. Quantum-mechanical calculations of structure and dynamics in terms of molecular fluctuations are beginning to reach a satisfactory level of approximation with the help of models, techniques, and computational capabilities derived from physics.

In both *cell physiology* and *neurobiology*, physical methods have long been crucial to understanding molecular transport, membrane structure, and signal processes in the brain, nerves, and muscles. New physical measurements of ion currents through single transmembrane molecular channels have provided the first direct access to the central molecular mechanisms that govern signaling processes in the brain and nerves.

Gene manipulation biotechnology now makes possible the systematic modification and production of potentially any protein. Thus, for the first time, rare proteins can be produced in quantities sufficient for structural studies by physical and chemical methods, and the expression of natural or modified proteins in living cells can be controlled to identify structure-function relations. The combination of biotechnology and biophysics offers a splendid promise for future productive research.

The multicellular *organization of the brain* and its principles of information storage and retrieval pose fundamental questions about physical networks that are currently attracting the attention of mathematical physicists. The theoretical physics of partially ordered systems has recently been applied with dramatic success to model aspects of the brain function. This could lead to significant interdisciplinary synergism involving the fields of neuroscience, statistical physics, and computer science, with implications extending to robotics and artificial intelligence. Perhaps ultimately the understanding needed to treat organic failures of the brain will emerge.

One might say that physics has advanced to a level on which it can now begin to address the imposing complexity of fundamental biological science at both molecular and many-body organizational levels. Yet institutional organization of both education and funding for biological physics often seems to impede progress at this fruitful interface. Few university physics departments accommodate biophysics. Biophysics is incorporated effectively in many biological science research programs, but the cross-fertilization between modern physics and biology does not often seem to be adequately supported. We can point to an opportunity here for effective interdisciplinary interaction through the funding of interdisciplinary centers that parallels that initiated so effectively in materials science 20 years ago.

Physics and Materials Science

In the past three decades, materials science has developed as an independent discipline from a fusion of metallurgy, chemistry, and ceramics engineering with aspects of condensed-matter physics. Today, at their common boundary, the fields of materials science and condensed-matter physics are distinguishable primarily by the viewpoints of their complementary educational disciplines.

The interface between physics and materials science is continuously innovative. The spectrum from basic problems to applications in technology is truly continuous. The challenge of problems in materials