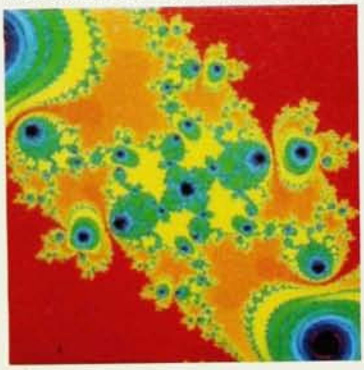
Enlargement of a region of the Mandelbrot set, which is useful for understanding chaotic systems. (Courtesy of John H. Hubbard and Homer Smith, Cornell University.)



Scientific interfaces and technological applications

Six of the Brinkman volumes are devoted to the major subfields of physics. However, even the casual reader of those volumes will quickly see that the division of physics into subfields is a somewhat arbitrary exercise: Particle physicists do cosmology, cosmologists do nuclear physics, nuclear physicists do atomic physics and so on. Even more striking is the degree to which physics contributes to and benefits from other sciences. Whole industries also trace their roots to recent research in physics. Modern technologies such as microelectronics and optical communication would be impossible without the aid of modern physics. Physics has also played a pivotal role in the development of national defense systems and in arms control. The physics survey volume entitled *Physics Through the 1990s: Scientific Interfaces and Technological Applications* explores the profound impact physics has had on society and the economy through its interfaces with other natural sciences and its applications to technology, medicine and national defense.

The panel identifies a dozen major interfaces of physics with other disciplines: biology, chemistry, materials science, geophysics, computational physics, mathematics, microelectronics, optical information technology, instrumentation, energy and environmental preservation, national security and medicine. Highlights include:

Biological physics. The tools and techniques of physics have always been applied to the study of life. Biophysics, however, goes beyond the application of physical methods to biological systems. For example, the concepts of theoretical physics are essential in the study of biopolymers—proteins, DNA and RNA. The structure and function of these essential molecules now seem to be within the grasp of first-principles quantum-mechanical computations. The detailed study of how ions are transported across cell membranes is essential to the understanding of cell physiology and neurobiology. The organization of the brain and its principles of computation and information storage and retrieval pose fundamental questions that are attracting the attention of mathematical physicists.

Physics and materials science. Research in new materials, processes and analytical methods relates to many areas of physics. Ion-beam etching, sputtering and molecular-beam interactions with surfaces involve plasma physics and atomic physics. Atomic physics also provides analytical methods in materials science—such as Rutherford scattering and particle beams. As statistical physics has succeeded in the analysis of partially ordered many-particle systems, the understanding of glasses and amorphous materials has advanced. The physics of the amorphous state is a topic of great current interest, attracting both fundamental and applied investigators. The dynamical theory of nonlinear systems is an extremely lively topic in mathematical physics with immediate applications to important problems in materials science, including crystal-growth instabilities and the dynamics of structure modulation.

Chemistry. It is often difficult to distinguish chemical physicists from physical chemists. The panel describes the enduring, ever changing interface between these two closely related fields. Tunable lasers have made possible spectroscopies of spectacular sensitivity as well as new strategies for observing unstable and transient states. The understanding of surfaces is an active area of collaboration with important applications to catalysis. Fluids formed of large, chemically complex molecules pose a formidable array of challenges. Of great current interest are the liquid crystals, formed by strongly anisotropic molecules, that exhibit simultaneously some properties of solids and of liquids. Collaborations between solid-state physicists and synthesizing chemists have resulted in novel, electrically conducting polymers that may be sources of new or enhanced phenomena, including superconductivity, charge transport and nonlinear response.

Geophysics. Geophysics interacts with physics through physicists who become geophysicists and through geologists' adoption of physics-based methodologies rather than via the collaborative, interdisciplinary research of other fields described by the panel. An exception is the study of turbulence: Geophysical fluid dynamics presents problems that test the fundamental understanding of turbulence and disordered nonlinear systems in general.

Finding accurate methods to measure geologic variables is a challenging problem. The limited accessibility of the interior of the Earth, the depths of the seas and the heights of the atmosphere and the sheer volume of data

Panel on Scientific Interfaces and Technological Applications

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Peter Eisenberger, Exxon Research and Engineering Company
Mitchell Feigenbaum, Cornell University
Kenneth A. Jackson, AT&T Bell Laboratories
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William H. Press, Harvard University
Donald Turcotte, Cornell University
Alexander Zucker, Oak Ridge National Laboratory

Protein diffraction pattern. Today's powerful x-ray sources and computers permit elucidation of the structure of very large proteins at high resolution from intricate patterns such as this.

call for heroic experimental measures. Measurement technology draws heavily on space science as well as new physics.

Detailed knowledge of the structure of the Earth's core is vital for testing the theory of plate tectonics, but only about half of the Earth's interior can be charted with basic seismography. Ocean-bottom seismology, only now becoming possible, will expand that fraction. Laboratory measurements at ultrahigh pressure of the properties of rocks and minerals today provide the primary basis for determining the equation of state of the Earth's interior.

Early terrestrial-mapping methods included long-baseline interferometry, seismology, measurements of gravity and terrestrial magnetism, sonic ocean probing and atmospheric probes. Recently these have been supplemented by laser altimetry, precision radar, remote optical and physical sensing from Earth satellites and planetary probes, mechanical-reflection probes, and electromagnetic probes. The huge mass of data from these investigations can only be digested by large-scale computers. Computer-assisted tomography, developed for imaging the human body, is now being used to depict the interior of Earth and its oceans.

Mathematical and computational physics. Physics has alway relied on mathematics to express the basic orderliness of the universe. That reliance is now greater than ever: The nonlinear gauge-field theories of elementary-particle physics and the study of chaos place unprecedented demands on the mathematician and the physicist. It is not uncommon now for each to make contributions to the other's field.

The development of mathematical physics is fostered by the development of powerful computers. Many of the important properties of nonlinear systems and the transition to chaos were first discovered through "numerical experimentation" on computers. Elementary-particle physicists are using computers to wrest information from their intractable equations.

In addition to the above-mentioned interfaces the panel discusses the fruitful transfer of physics to technology and cites as examples the microchip, optical information technology and the numerous applications of physics to medicine, such as the CAT scanner, nmr imaging, PET scanners and more. It also mentions the important roles physics is playing and must continue to play in the development of new energy sources—solar, fission and fusion—as well as its contribution to essential technology.

The panel forcefully makes its point that the intellectual boundaries between physics and other sciences and between physics and technology are vanishing. Practitioners in these fields have long known this, following their natural curiosities while ignoring inconvenient distinctions. Policy makers, the panel concludes, should be doing more to get into step with these trends.

Division among academic disciplines is important for the maintenance of standards of quality in education, the panel states, and these disciplines have proven to be adaptable to change. Nevertheless the time may have come to initiate a strategic reconsideration of the formal disciplines to reflect modern science and technology. Consequently the panel writes, "We recommend that universities and funding agencies organize to accommodate and enhance the engineering–physics interface in both education and research."

Believing that, by its very nature, innovation is unpredictable, the panel stresses the importance of basic research: Basic physics research should be spread from the universities and a handful of large companies to smaller companies because small firms also can benefit from the intellectual stimulation and technology transfer inherent in basic research. To this end, the panel writes, "Tax policy should encourage both in-house industrial research and cooperative research programs with universities and government laboratories. Antitrust laws and policies should be modified or reinterpreted to facilitate and encourage industrial and institutional collaborative research combinations and associations that enhance the national competitive position and economic welfare."

Citing the successful history of materials science, whose birth was midwifed in interdisciplinary research centers, the panel recommends that "universities should encourage the formation of interdepartmental, interdisciplinary research and research centers to attract and utilize interdisciplinary research funding to transcend communication barriers among the traditional disciplines and provide multidisciplinary and trans-disciplinary education."

—Bruce Schechter □