BPA News

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The Physics of Materials

by Venkatesh Narayanamurti, Chair, Committee on Condensed-Matter and Materials Physics and Dean of Engineering, UC Santa Barbara

THE Committee on Condensed-Matter and Materials Physics, which was commissioned by the BPA to prepare a volume of the new survey, *Physics in a New Era*, has just completed a short preliminary report entitled *The Physics of Materials.* The report highlights a number of areas of forefront research and also points out in a popular format the role that this field plays in our lives. The following article draws from the text of the report, which is available in printed and electronic form from the BPA (see www.nas.edu/bpa).

Introduction

Condensed-matter and materials physics has played a key role in many of the scientific and technological revolutions that have changed our lives so dramatically in the last fifty years. The years ahead will see equally dramatic advances, making this an era of great scientific excitement for research in this field. It is also a time of stress on the institutions that support the field. The goal of the report *The Physics of Materials* is to give the reader a sense of what condensed-matter and materials physics is about—of the excitement that scientists feel, the importance of their work, and the challenges they face.

Within our lifetimes, improvements in our understanding of materials have transformed the computer from an exotic tool, used only by scientists, to an essential component of almost every aspect of our lives. Computers enable us to keep track of extraordinarily complex data, from managing financial transactions to forecasting weather. They control automobile production lines and guide aircraft around the world.

During the same period, telecommunication has evolved from rudimentary telephone conversations to instantaneous simultaneous worldwide transmission of voice, video images, and data. The cellular phone is even unleashing us from telephone wires.

Almost every American can now enjoy, while relaxing in the living room or driving the car or even while jogging, music of a quality that in previous generations was available only to concertgoers.

Just a few generations ago, a trip across the United States was a great adventure. Today, jets whisk us safely across the continent or the oceans in only a few hours.

Making these extraordinary accomplishments possible are a wide variety of polymeric, ceramic, and metallic materials, as well as the transistor, the magnetic disk, the laser, the light-emitting diode, and a host of other solid-state devices. The development of these materials and devices depended on our ability to predict and control the physical properties of matter. That ability is the realm of condensed-matter and materials physics (CMMP).

Fifty years ago, the major intellectual challenge facing researchers in CMMP was to understand the physical properties of nearly perfect single crystals of ele-

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In this issue:

BPA Gathers on the West Coast

Report of the Committee on Optical Science and Engineering Unveiled

THE Board on Physics and Astronomy held its semiannual meeting at the Academies' Beckman Center on the UC Irvine campus on November 1-2. Just before the BPA convened, there were several special meetings at the Center to launch new activities.

Physics Survey Overview

On October 31, former BPA chair David Schramm convened a group to plan the *Overview* volume of the new survey, *Physics in a New Era.* Most of the components of the survey are completed or in progress, and it is time to begin work on its capstone, the *Overview*, which will summarize the conclusions and priorities of the various branches of physics and address a number of broad unifying themes and common issues that affect all of physics. The group wrestled with the question of how to identify priorities for all of physics in a way that does not involve comparing one branch of physics directly with another.

New Survey of Astronomy and Astrophysics

On the morning of November 1, Board member Tony Readhead convened a distinguished group of astronomers to begin preparations for the next survey of astronomy and astrophysics. Among the participants was John Bahcall, chair of the last Astronomy and Astrophysics Survey Committee, which published a report entitled *The Decade of Discovery* and which carried on the tradition of the astronomy community of setting clear priorities for the field. George Field, who chaired the committee that prepared *Astronomy and Astrophysics for the 1980s*, attended. Also present were the cochairs

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The Board on Physics and Astronomy is a continuing interdisciplinary body with expertise spanning the various subfields of physics, astronomy, and astrophysics. It serves as a focal point in the National Research Council for issues connected with these fields. The activities of the Board are supported by funds from the National Science Foundation, the Department of Energy, the Department of Defense, the National Aeronautics and Space Administration, the National Institute of Standards and Technology, and private and other sources.

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of the NRC's Committee on Astronomy and Astrophysics, which was created in response to the recommendation of the Bahcall Report that a continuing committee be established to carry out short-term studies in between the major decadal surveys. The chairs of the sponsoring Boards—the Board on Physics and Astronomy and the Space Studies Board—participated along with former Commission member Jerry Ostriker. With support from the National Science Foundation and the National Aeronautics and Space Administration, the new decadal survey is expected to get under way early next calendar year.

BPA Meeting

The Board itself was convened in the afternoon of November 1 by newly-installed BPA Chair Robert Dynes, faculty member of the Physics Department and Chancellor of the University of California San Diego campus. New BPA members Val Fitch (Princeton), Kathleen Taylor (GM R&D Center), and George Whitesides (Harvard University) were welcomed. The Board congratulated fellow-member Steven Chu on his receiving the Nobel Prize for his work in trapping and cooling of atoms.

The Board is developing studies in a number of cross-cutting areas: education, computational physics, and biological physics.

Education

Leon Lederman reported on a program-initiation meeting on education to develop a focus on education for the physics survey that he recently led. Because an important audience for the physics survey will be physics departments, one of the major topics to be addressed by a study of physics education in the context of the physics survey will be the role of the departments in improving physics education for undergraduates, including not only those who are potential physics majors, but also students who will study in other areas of science and those who will study humanities and liberal arts. There are many new approaches and also new ways to identify and evaluate what works. The physics survey should also address the role of faculty members in improving high-school science education. Could a high-school physics course serve as a foundation for learning other natural sciences? Should high-school science be taught in a way that blends the sciences and is not bound by disciplinary boundaries? Can the university community be mobilized to help high-school teachers and administrators to address these issues? The Board enthusiastically endorsed pursuing these issues and encouraged Dr. Lederman to continue developing a plan for a component of the physics survey treating education.

Computational Physics

David Arnett reported on a program-initiation meeting that he led to consider a study of computational physics. The group concluded that computation is playing such an important role in physics, both in simulation and modeling as well as data integration and visualization, that there should be a study of this area as part of the physics survey. The Board encourage Dr. Arnett to work with the BPA staff to develop a study plan.

Biological Physics

Steve Chu discussed biological physics with the Board. He recounted the results of a program initiation meeting that Steve Block chaired, which concluded that a study of the "New Biology" should be undertaken. The study that Block's group developed is motivated by the need for the field of biology to reinvent itself in the post-genomic era, moving toward a more quantitative approach. The Board applauded this result and encouraged the NRC's Board on Biology to take the lead in developing this study. Dr. Chu emphasized that physicists have made and continue to make important contributions to biology and that therefore, there should be a component of the physics survey that addresses "biological physics." The Board encouraged Dr. Chu, Ivar Giaever, and Hans Frauenfelder (attending the BPA meeting on behalf of the NAS Physics Section) to develop a plan for a study of biological physics.

Studies in Progress

The Board heard reports on the progress of a number of studies (some of which are near completion) including:

- Optical science and engineering - Charles V. Shank
- Elementary-particle physics - Bruce Winstein
- Nuclear physics - Sam Austin
- Condensed matter and materials physics - Venky Narayanamurti
- Gravitational physics - James Hartle

Optical Science and Engineering

The Committee on Optical Science and Engineering has nearly completed its work. From March 1995 to March 1996, the Committee conducted a series of six workshops with a use/application orientation:

- Health and life sciences
- Manufacturing
- Information technology
- Energy, space, environment, optical sensing
- Research and education
- Defense

Over the last year, COSE has worked on synthesis of the results of the workshops , formulation of conclusions and recommendations, and preparation of an overview chapter that summarizes the results of the study.

The chapters of the report are as follows:

1 Overview
2 Optics in Information Technology
3 Optics in Health Care and the Life Sciences
4 Optical Sensing, Lighting, and Energy
5 Optics in National Defense
6 Optics in Industrial Manufacturing
7 Manufacturing Optical Components and Systems
8 Optics Research and Education

Dr. Shank reviewed some of the findings in these areas. Among the most impressive of these has to do with the role of optics in "tera era" information technology of the future. In information transport, optical fiber will play a crucial role in establishing a terabit per second national long-haul network backbone. Computer technology is headed toward tera-operations per second, and optical technology will play various roles in these developments. For example, interchip communication may use optical techniques. And optics will play a crucial role in terabyte data banks. These developments will have a growing impact in the commercial sector, but a roadblock in the path to individual consumer access to the full power of the global information network is providing an infrastructure for broadband data transmission to the home. Here again, optical technology holds a possible answer.

Optics is also affecting health care in dramatic ways. Optical tools for biotechnology show promise in gene sequencing. New understanding of light-tissue interactions will lead to better laser surgical techniques. And optics will enable advances in minimally invasive therapies. NIH has an opportunity to play a major role in these developments.

One of the greatest possible impacts of optics is in the area lighting, where revolutionary changes are in the offing. Lighting accounts for about 20 percent of U.S. electricity consumption. High-technology lighting offers various options for improved efficiency that, taken together, could cut power consumption, perhaps by as much as half over the next decade.

Optics plays a central role in modern warfare. Military systems and functions featuring optical applications include missile guidance, night vision, laser gyros, laser weapons, and satellite surveillance.

Manufacturing of conventional optics is making great strides. There has been a revolution in optical-design software. There is a growing demand for mass manufacturing techniques that enable cheaper, faster, and more flexible production processes for optical components and systems.

Optics has many applications in industrial manufacturing, including optical lithography of semiconductors, laser materials processing, rapid prototyping, sensors for real-time monitoring and control, optical metrology, and lasers for alignment and guidance.

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U.S. National Committees[3]

[1] In cooperation with the Space Studies Board.

[2] In cooperation with the National Materials Advisory Board.

[3] See www.nas.edu/bpa for more information.

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ments, simple compounds, and alloys. Today our challenge is to extend that understanding to much more complex forms of matter—high-temperature superconductors, multicomponent magnetic materials, disordered crystals, polymers, glasses, and to more complex phenomena like the fracture of solids and the continuous hardening of glass as it cools. Ever in view in today's CMMP is another scientific revolution, the dramatic change under way in the biological sciences. Great opportunities lie ahead as condensed-matter and materials physicists increasingly work together with biological scientists.

Technology in Daily Life

The second part of the report illustrates the vital impact of CMMP on our daily lives. It consists of a brief story—a few simple events that happen every day—accompanied by descriptions that highlight a sampling of the scientific and technological advances in CMMP that make those everyday events possible. The sidebar (Figure 1) illustrates the role of compound semiconductors in making possible the cellular telephone and the pocket pager, both increasingly familiar fixtures of everyday life.

The Research Endeavor

Part 3 of the report explores the nature of the CMMP endeavor itself. CMMP is a diverse, evolving, interdisciplinary field linked strongly to other science and engineering disciplines, which benefit from and contribute to its successes. Indeed, CMMP is distinguished by its extraordinary interdependence with other science and engineering fields. Its practitioners include those who make and refine new materials, those who seek to understand such materials at a fundamental level through experiments and theoretical analysis, and those who apply the materials and understanding to make new devices. This work is done in universities, in industry, and in government laboratories.

Part 3 speaks, as well, of a field in transition. New linkages with disciplines such as polymer chemistry and the biological sciences are growing in importance.

Fifty years ago, the transistor emerged from this area of physics. High-temperature superconductivity was discovered by condensed-matter physicists, as were the fascinating low-temperature states of superfluid helium. Scientists in this field have long-standing interests in essentially all aspects of magnetism and magnetic materials. They investigate the properties of glasses, polymeric materials, granular materials, and composites in which diverse constituents are combined to produce entirely new substances with novel properties. They are reaching out to researchers in the earth and atmospheric sciences because they share interests in topics such as friction, fracture, and fluid flow. The outreach to biology and the study of biological materials are now beginning in a serious way.

Hardly any other field of science so seamlessly spans the whole range between the most basic research and the most applied. Advances in basic research inspire new ideas for applications, and application-driven technological advances provide tools that enable new fundamental investigations. At the same time, technological problems raise questions that demand new fundamental insights. For example, with new fundamental understanding of nonequilibrium phenomena, we may soon see a qualitative improvement in our ability to predict and control complex properties of the structural materials used to manufacture everything from airplanes and bridges to electronic devices. Technological advances provide tools such as synchrotrons, neutron sources, electron microscopes, high magnetic field facilities, computers, and

COMPOUND SEMICONDUCTOR ELECTRONICS

Silicon is the material underlying most electronics, but compound semiconductors composed of more than one element, such as gallium arsenide (GaAs) and silicon germanium (SiGe), have advantages that can lead to devices with intrinsically higher speed and lower noise. The worldwide market for compound semiconductors is estimated to be $750 million in 1996, and it is growing at the rate of 40% per year. Discrete components are now widely used in the low-noise receivers of cellular telephone handsets, in addition to the specialized high-speed microwave applications for which they have long been the materials of choice.

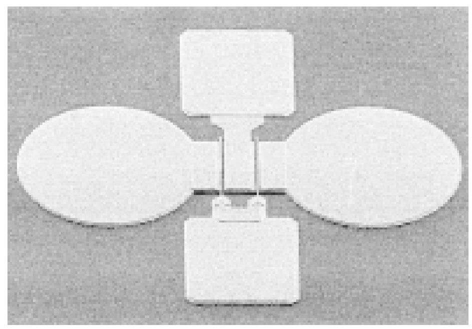

FIGURE 1 A high electron-mobility transistor (HEMT) such as those used in cellular telephones. The round bonding pads are 100 microns in diameter, roughly the size of a human hair. The gate of the transistor, just 0.05 microns across, appears as the two narrow lines in the center of this scanning electron micrograph. (Courtesy of Sandia National Laboratories.)

Compound semiconductors such as GaAs, SiGe, and gallium nitride (GaN) are key to the development of the next generation of wireless telephones, which will use higher frequency microwaves in order to transmit more information. GaN transistors, for example, are characterized by high breakdown voltage and great robustness. A potential high-volume application for such transistors is in transmitter power amplifiers for wireless base stations.

Pushing the limits of semiconductor materials technology is essential for increasing the speed of transistors and advancing our ability to modulate lasers for high-speed optical information transmission. Because compound semiconductors are composed of more than one element, they promise a vastly increased range of materials from which to select those with desired electronic properties. This promise can be realized with manufacturing techniques such as molecular beam epitaxy, which allows the repeated, controlled, precise growth of one material on another in single atomic layers, producing compound layered materials not seen in nature. In the future, the use of novel forms of microscopy for fabrication and testing will determine our ability to design and build such structures on the atomic scale—a scale on which the motion of electrons is governed by quantum mechanics.

scanning probe microscopes. These tools, in turn, provide unprecedented opportunities to investigate materials on the atomic scale, leading to fundamental discoveries that drive both science and technology. The new physics of the fractional quantum hall effect, for example, was made possible by new materials fabrication technology. (See the sidebar, Figure 2.) The study of matter under extreme conditions has led both to fundamental and practical breakthroughs.

Several of the most profound conceptual developments in science have occurred in CMMP in the last two decades. The so-called "renormalization-group" theory of critical fluctuations in condensed matter has helped us understand phenomena as varied as phase transformations, the interactions between elementary particles, and the fluctuations of the stock market. Chaos, turbulence, and pattern formation are other core concepts in this field that have had wide-ranging implications across the world of science. The historic role of condensed-matter physicists, ever since the emergence of quantum electronics and the transistor, has been to discover new concepts and phenomena and to develop their new knowledge in ways that are meaningful for fundamental advances in many fields and for practical applications.

THE FRACTIONAL QUANTUM HALL EFFECT

The fractional quantum Hall effect is an example of beautiful and fundamental new physics made possible by technological advances in the fabrication of artificially structured materials. It takes place in a two-dimensional electron "gas" produced in a transistor-like device subjected to extreme conditions of high magnetic fields and low temperatures. Under these conditions, electron correlations become dominant. The basic observation is a precise quantization of the Hall conductance with the unusual property of being described by a quantum number that is fractional rather than an integer.

The application of a strong magnetic field at low temperature induces large numbers of vortices ("whirlpools") that attach themselves to the electrons to form composite objects, which condense into a special quantum "fluid." This fluid of composite particles has the bizarre property that the low energy excitations consist of a single vortex that binds a fraction of an electron charge. These objects have recently been observed through direct measurement of their fractional charge and by tunneling experiments in which an electron added to the system is seen to break up into three excitations, each with one-third of the charge. Theoretical work on this problem has led to profound and intellectually exciting new concepts and techniques with applications both in other areas of condensed-matter physics and in quantum field theories studied in elementary particle physics. We are familiar with the idea in high-energy physics that certain elementary particles such as protons are actually composite objects made up of fractionally charged quarks. These quarks can be observed in collisions at very high energies (or equivalently, high temperatures) carried out using particle accelerators. In condensed matter physics, one does the reverse: the analog of the accelerator is the refrigerator. At sufficiently low temperatures, in a strong magnetic field, electrons added to a quantum Hall system break up into fractionally charged elementary vortex excitations. This, then, is a fundamentally new form of conduction in an artificially created, layered material.

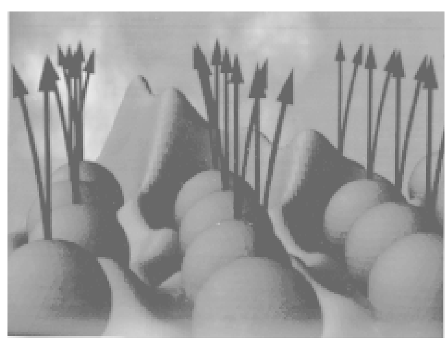

FIGURE 2 A pictorial representation of the many-particle state that underlies the fractional quantum Hall effect. The height of the landscape represents the amplitude of the quantum wave of one electron as it travels among its companions (balls). The arrows indicate the vortices induced by the magnetic field. These vortices attach themselves to the electrons to form composite particles. (Courtesy of Lucent Technologies Bell Laboratories.)

What does the future hold for condensed-matter and materials physics? There must be many surprises in store for us. Consider the fact that essentially none of the most important discoveries in this area made in the last decade were anticipated in the 1986 National Research Council report *Physics Through the 1990s.* And the pace of scientific change, especially when viewed on an international scale, is now accelerating.

A particularly dramatic surprise was the discovery in 1986 of high-temperature superconductivity, which disproved a consensus then growing among scientists that superconductivity could exist only at temperatures very near absolute zero. Now, just over a decade later, we are beginning to see commercially marketed devices based on superconductivity at easily accessible liquid-nitrogen temperatures, and we can look forward to decades of new developments. Even more important, condensed-matter and materials physicists have learned that chemically complex materials, like the new superconductors, can have extraordinarily interesting properties. The study of such complexity in solids is emerging as a whole new style of inquiry.

A different kind of unanticipated complexity is emerging in artificially structured materials, engineered with features so small that they behave like artificial atoms. These structures are candidates for the next generation of computing elements, but their potential uses in both science and technology go far beyond computing as we know it. As we learn how to assemble increasingly complex structures from more and more complex building blocks, perhaps even from biological molecules, we can anticipate a whole new world of scientific phenomena and practical applications.

An Era of Change

The evolution of CMMP is taking place within an evolving national and international context, as described in Part 4 of the report. The great industrial laboratories, so prominent over the last half century, have shifted the scale, scope, and emphasis of their R&D investments in CMMP to adjust to changes in the global marketplace. Industry is looking more and more to universities and government laboratories to perform basic research that will

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lead to the next generation of technology. Yet these very academic and government institutions are themselves facing considerable stresses that limit their abilities to respond to new demands.

Part 4 also discusses issues arising from the growing dependence of CMMP on shared large and medium-size experimental facilities. Increasingly sophisticated equipment has become necessary for scientific innovation, from electron-beam instruments to giant x-ray synchrotrons. These facilities are essential for continued advances in the invention, understanding, and control of increasingly complex materials. They are required for a broad range of scientific and technological endeavors, not only in CMMP but also in many other fields of science and in industry. But funding large facilities strains the resources of the agencies that have traditionally provided research support to universities and government laboratories, even as those institutions are being asked to play a broader role.

The great industrial laboratories—the engines that have driven technology for the past half century—have adjusted to the realities of the new global marketplace and changed both the scale and scope of their long-term R&D investments in the physical sciences. Under pressure to balance the federal budget, the U.S. government is reducing its discretionary expenditures, the category that includes federal support for science. At the same time, many other countries are increasing their investments in long-term R&D. The debate about the appropriate roles in R&D of industry, government laboratories, and the universities is set against this backdrop of constrained resources and increased global economic competition.

In the next century, the United States will need to respond to world tensions arising from economic competition, regional military conflict, competition for energy and other strategic resources, and global environmental issues. These new international challenges differ from those of the Cold War past, and addressing them cost effectively will require continued scientific advances. National issues related to security, the environment, and energy resources will also need to be confronted. Condensed-matter and materials physics will play a pivotal role in ensuring the nation's prosperity in this new world.

This report demonstrates that condensed-matter and materials physics lies at the heart of modern technology. Advances in communications, computing, medicine, transportation, energy, and defense have all been enabled by new materials and materials-related phenomena. Research in condensed-matter and materials physics, pushing forward the frontiers of both science and technology, provides much of the fundamental underpinning for these advances. Its success has been one of the great sagas of the 20th century.

As we enter the new millennium, the field of condensed-matter and materials physics is evolving in several important directions. It is becoming increasingly interdisciplinary, with progress often being made at the interfaces with other disciplines, such as biology, chemistry, engineering, materials science, and atomic and molecular physics. Partnerships across disciplines and among universities, government laboratories, and industry have become essential to assemble the resources and diverse skills necessary to continue advancing our knowledge. The emergence of national facilities, from atomic-resolution microscopes to powerful synchrotron and neutron sources, has transformed both the practice and the substance of the field. These developments foreshadow a condensed-matter and materials physics community more closely connected with industry and with the rest of science, and armed with experimental and computational capabilities that were not even imagined just a few decades ago.

The 21st century will bring significant challenges to condensed-matter and materials physics. Foremost among these challenges is ensuring the future vitality of the field and its continued ability to enhance our quality of life. The shift of the major industrial laboratories away from long-term, fundamental research in the physical sciences leaves a significant gap in the nation's scientific infrastructure and its ability to transform the fruits of research into applications. The economic impact of this shift may not become apparent for decades, because of the time required for fundamental scientific advances to be incorporated into new products. If U.S. industry no longer can support basic research at the levels it once did, then the realities of global economic competition place the burden for support of such research squarely on government. Our nation must move quickly to determine the scale and form of this governmental responsibility.

Innovation is the key to developing breakthrough technologies. It must continue to flourish despite the resource constraints that are sending shock waves through the R&D system. Constrained resources mean that hard choices must be made, but the system must adapt in a way that preserves the nation's ability to innovate and enables us to meet the challenges of the future.

Progress in condensed-matter and materials physics, as in many other scientific fields, will require continued investment in major facilities for experiments in such areas as neutron scattering and synchrotron radiation. These facilities provide capabilities far beyond those available in individual laboratories. Though they have been developed and supported primarily by the condensed-matter and materials physics community, they also serve thousands of scientists and engineers in other endeavors, such as structural biology and environmental science. The construction and operational costs of large facilities, however, force us to consider carefully their budgets relative to those for other R&D initiatives and to look more closely at the role and impact of the internationalization of science.

Finally, increased cooperation will be required among universities, government laboratories, and industry to leverage existing resources and to ensure the effective integration of science and technology. These interactions will be facilitated by modern communication and information technologies.

We face an era of vast opportunity for condensed-matter and materials physics and the technology it enables. Just as the transistor, the optical fiber, and the solid-state laser have strengthened our economy and changed our lives, new developments in quantum engineering, nonequilibrium phenomena, and biomaterials (to name just a few highlights) hold out the promise of revolutionary breakthroughs in the next century. To fulfill this promise, the condensed-matter and materials physics community will need to build on the unique strengths of universities, government laboratories, and industry, finding new ways to meet the challenges of our changing world.■

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In the area of basic research, there have been a number of breakthroughs, including control and detection of single atoms and molecules, new femtosecond techniques, nonlinear optical materials, and high-frequency sources and components.

The COSE report is expected to be published early in 1998.

Elementary-Particle Physics

The report of the Committee on Elementary-Particle Physics, chaired by Bruce Winstein of the University of Chicago, has cleared the National Research Council's review process and is about to go to the National Academy Press for publication. The report explains the motivations that drive the field, describes its connections to other branches of physics and science, outlines a strategy for addressing the principal questions, and shows how accelerator and detector development have created technologies that have brought benefits to society. One of the principal questions in this area of research is "What is the origin of mass?" The standard model of particle physics, which has successfully solved a number of vexing theoretical difficulties and at the same time explained a vast array of experimental results, employs a new mechanism to explain how the particles in the theory acquire their masses. The mechanism involves the so-called Higgs boson. Researchers in this field believe that there is powerful evidence that the next generation of experiments will begin to reveal more about how the mass-generating mechanism works and whether new ultrastrong forces are involved. Theorists have developed a new approach to describing elementary particles and their interactions called "string theory." Much effort has gone into understanding this new theoretical domain and connecting it with experimental results. String theory, unlike all previous theories, can incorporate the fourth force, gravity, in a consistent manner. It also predicts the existence of supersymmetric partners to the presently know spectrum of elementary particles. Such a theory will be necessary if an understanding of the details of the Big Bang (the event that created the Universe) is to be reached. To explore these ideas, experiments are needed that probe the energy domain connected with mass generation. The international Large Hadron Collider, to be built at the European high-energy laboratory CERN, will host a number of these experiments, and the U.S. community is heavily involved. There is a joint agreement between the United States Department of Energy and CERN that formalizes U.S. participation. The elementary-particle physics community foresees the need for an accelerator that goes well beyond the energies attainable at the LHC; there are many possibilities, and the report outlines a strategy for developing several of them.

Nuclear Physics

Sam Austin, a member of the Committee on Nuclear Physics, another component of the physics survey, reported on the progress of that study, chaired by John Schiffer of the University of Chicago. Nuclear physics is a rich and complex area of research and the committee is assessing its many components. Of particular interest is the study of the quark-gluon plasma, which is expected to be generated when nuclei are collided at high enough energies so that the quarks that are bound into the individual neutrons and protons within the nucleus become deconfined. An accelerator called the Relativistic Heavy-Ion Collider is under construction at Brookhaven National Laboratory to explore the physics of the quark-gluon plasma.

Condensed-Matter Physics

Venkatesh Narayanamurti, chair of the Committee on Condensed-Matter and Materials Physics, described the progress of his committee and presented the Board with copies of a research briefing on this topic that his committee has prepared to acquaint a broad audience with the role of materials physics in everyday life. The lead article in this issue of *BPA News* presents some of the material from this briefing, which is available in its entirety from the BPA in printed form or in electronic form on the web. (The BPA's website can be found at www.nas.edu/bpa.)

Gravitational Physics

The Committee on Gravitational Physics is just getting started under the leadership of James Hartle. This area has been given a separate study in the physics survey because of the growing links to cosmology and elementary-particle physics and because of the major facilities that are under construction or consideration for the future.

Helium Study

Bob Richardson briefly commented on the study of the impact on S&T of the legislated privatization of the helium reserve. The Department of Interior has commissioned the BPA to study this issue in response to a Congressional mandate.

Materials Facilities

Tom Russell commented on the planned study of agency roles and responsibilities in managing materials facilities, noting that the recently-completed DOE study concluded that it is important to maintain operation of all the synchrotron facilities, including first generation ones, because of the great demand from the user community.

Next BPA Meeting

The next meeting of the Board on Physics and Astronomy is scheduled for Spring of next year, on April 24-25, just before the annual meeting of the National Academy of Sciences. ■

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New Report:

•*The Physics of Materials.* Available from the BPA and on the BPA website.

Coming soon:

•*Harnessing Light* (report of the Committee on Optical Science and Engineering)

•*Elementary-Particle Physics*