Issues in Physics & Astronomy at the BPA

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A U.S. Role in Rare-Isotope Science

T.I. Meyer, BPA Staff

Over 10 years ago, U.S. nuclear scientists proposed construction of a rare-isotope accelerator in the United States. Such a facility would enable experiments to elucidate the structure of exotic, unstable nuclei and provide critical information needed to explain nuclear abundance in the universe. Studies by the NSF-DOE Nuclear Science Advisory Committee supported this proposal, initially termed the Rare Isotope Accelerator (RIA). In 2005, DOE and NSF, seeking an independent scientific assessment, asked the NRC to define the science agenda for a next-generation U.S. Facility for Rare Isotope Beams (FRIB). As the study began, DOE announced that the budget for what was then the RIA should be reduced about in half. The study then shifted to an evaluation of the science that could be accomplished at a facility so reduced in scope. The revised charge also directed the NRC to evaluate the scientific impact of a rare-isotope beams facility in the overall context of the national and international nuclear physics programs. The scope of the committee's charge explicitly precluded recommending and comparing FRIB to other potential U.S. initiatives in nuclear science.

These developments in facility definition and projected schedule presented the committee with two main challenges. First, an effort that had started as an analysis of the most compelling intellectual territory addressed by a well-defined facility was transformed into an opposite effort, with the committee focusing first on the scientific questions of highest importance and then speculating about the technical capabilities that a next-generation facility would need to make progress. Second, with a shift in the anticipated construction start from 2008 to 2011 at the earliest, the committee was forced to guess at not only the scientific developments more than a decade in the future but also at the evolving scientific activities of other facilities and nations around the world.

To better understand the potential impact on the scientific agenda of such a cost reduction, the committee heard views from some of the proponents of a US-FRIB in a public meeting; these individuals gave the committee their views on production techniques and beam intensities that they judged to be technically feasible. The primary trade-off indicated in these presentations was a modest reduction in the quantity and diversity of possible isotopes, and a significant reduction in the multiuser aspects of the facility.

In developing its conclusions regarding a U.S. facility for rare-isotope beams, the committee took into account the worldwide portfolio and the likely time frame in which a FRIB might begin operations

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In this issue:

Ethanol as a Biomass Fuel

Matthew Bowen, Christine Mirzayan Science & Technology Policy Graduate Fellow

Ed. Note: The National Academies sponsors a quarterly fellowship program that brings doctoral students and graduates to Washington. Matthew Bowen, a recent Ph.D. from the University of Washington, joined the BPA for autumn 2006.

I hadn't come to the National Academies to learn about ethanol. As a Science and Technology Policy Graduate Fellow and recent recipient of a Ph.D. in theoretical particle physics, I was expecting to spend most of my time looking at reports on rare isotope accelerators and NASA missions. But in the first week of the fellowship program, when asked for a seminar topic, I proposed ethanol and soon found myself in charge of organizing the event.

Researching potential speakers put me in contact with staff from the Board on Energy and Environmental Systems, the Board on Agricultural and Natural Resources, and a number of National Academy of Science members. It also brought to my attention a paper ("Ethanol Can Contribute to Energy and Environmental Goals," Farrell et al. (2006) *Science* **311**: 506-508) by a former condensed matter physicist, Daniel Kammen, now a professor of public policy at the University of California at Berkeley. Kammen and his collaborators were attempting to definitively settle some of the environment and energy questions surrounding ethanol by directly comparing several studies to make clear what the differences between them were.

Specifically, the group adjusted all of the studies surveyed so that they conformed to a consistent system boundary. The unstated goal of Kammen's study was to move the debate over corn ethanol beyond the net energy balance question to focus instead on greenhouse gas emissions, reduction of petroleum consumption and the potential of

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Highlights of the Autumn Meeting of the Board on Physics and Astronomy

Caryn J. Knutsen, BPA Staff

The Board on Physics and Astronomy met for its annual fall meeting on November 4-5, 2006, at the Beckman Center of the National Academies in Irvine, California. Chair Anneila Sargent called the meeting to order, thanking everyone for being present and introducing the new board members. Vice chair Marc Kastner described the focus of this meeting: an overview of the *Physics 2010* decadal survey, completed reports, the reports in progress, and projects currently being conceived.

The discussion opened with a presentation on the EPP 2010 report *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics,* by Jonathan Bagger. He briefly reviewed the structure and content of the report, commenting that the United States is probably ahead of many of its world partners in terms of thinking globally about the conception of large research facilites as opposed to thinking globally only about the execution. He added that the international landscape is evolving and the United States may not be able to maintain its lead. Homer Neal provided an overview of the subpanel on university research programs that he is chairing for the NSF/DOE High Energy Physics Advisory Panel. A key issue faced by his panel is the rationale for universities to continue their involvement in elementary particle physics and what they can offer uniquely. The panel is also considering the balance between university-based research programs and those at the national laboratories.

Plasma 2010 committee chair Steven Cowley presented a status report on the project; he said that the committee's final report would be completed in Spring 2007. The Plasma 2010 committee has identified a host of exciting new opportunities in plasma science and engineering and expects to answer the question, "Are the communities and sponsoring agencies best positioned to take advanatge of these developments?"

Participating on behalf of the recently completed AMO 2010 report, *Controlling the Quantum World: The Science of Atoms, Molecules, and Photons,* Phillip Bucksbaum presented the report and thanked the BPA for the experience of co-chairing the committee. Ultimately, he noted, in science it is more important to pick the winners than to identify the losers; telling the government what the field needs, rather than how the agencies should do their jobs, is the more successful approach. The sponsors were quite pleased with the report; Dr. Bucksbaum was also invited to discuss the report and its organizing rubric of compelliing scientific opportunities presented in the form of questions with DOE's Basic Energy Sciences Advisory Committee.

Thomas Theis then presented a status report on the CMMP 2010 committee and its interim report, *Condensed-Matter and Materials Physics: The Science of the World Around Us* (see related article in this newsletter). Dr. Theis commented that the committee was examining trends over the past decade in the costs of research, focusing on graduate students and instrumentation; it is not clear that federal resources have been able to keep pace with the perceived escalation. The final report of the committee is expected in mid-2007 and will not only treat the topics of the interim report in more detail but will also provide guidance to the scientific community and the federal agencies on how best to move the research forward.

Jonathan Bagger led a discussion of a possible volume of *Physics 2010* that would focus on gravitational physics. Informal discussions with several agencies have been positive, he reported, but the scope of the projects needs careful consideration. He noted that in some key ways, the study of gravity represents one of the frontiers of fundamental physics: classical field theories and quantum field theories are related in intricate ways not yet understood. Gravitational phenomena also cut across both physics and astronomy, ranging from precision tests of the equivalence principle in the laboratory to the most energetic phenomena in the universe in the form of massive black holes in the center of active galactic nuclei. A study committee would have to take care to ensure that the scientific assessment and its recommendations would connect well with efforts in the next decadal survey of astronomy and astrophysics: topics such as dark energy, gravity waves, and inflation would have to be included. One proposal, he said, might to conduct the study as a subpanel of both the astronomy survey and the *Physics 2010* survey. Regardless of the final approach, he said, the fact that gravity physics is so encompassing is a tribute to how much the field has evolved.

Wick Haxton gave an overview of a possible nuclear physics volume of the decadal survey, to be called Nuclear Physics 2010 (NP2010). Professor Haxton described the long-range planning effort being undertaken by the nuclear science community under the auspices of the joint NSF/DOE Nuclear Science Advisory Committee. He suggested that NP2010 should not begin until after this community process is completed and that—if the NRC study were to add real value—it should (1) focus on framing nuclear physics within the broader context of the physical sciences and (2) examine the global context for the U.S. efforts and provide guidance on the U.S. role in the worldwide effort.

Allan MacDonald shared some observations about what an overview volume in *Physics 2010* might look like. For instance, attracting new people to the field and educating students are issues with which all physicists must grapple.

After breaking for lunch, committee chair Matthew Tirrell updated the Board on the progress of the MRSEC Impact Assessment Committee, a project that is examining the past and future roles of the NSF Materials Research Science and Engineering Center program in advancing materials research. The committee is grappling with the general issue of distinguishing the activities enabled by the center-based program from those with other support. The committee is finishing up its report and will likely send it to review in January 2007.

Committee chair Arup Chakraborty reviewed the progress of the Biomolecular Materials and Processes Committee (BMAP), stating that the committee is preparing for its third and final meeting. The charge to the committee was rather broad: "biomaterials" is much broader than just "biologically inspired" materials, the Board noted.

Rare Isotope Science Assessment Committee committee co-chair Stuart Freedman presented a status report on the progess of the committee. The committee is on track to release its report this autumn. [It has since been released; see article in this issue.]

Beyond Einstein Program Assessment Committee committee co-chair Charles Kennel then discussed the upcoming committee meeeting with the Board. He acknowledged the difficult task facing his committee and asked the Board for its assistance in reaching out to and engaging both the physics and astronomy communities (see related article in this issue).

Jose Onuchic gave an energetic presentation on the upcoming study on the forefronts of research at the intersection of the physical and life sciences. NSF, NIH, and DOE have agreed to support this project; the BPA is collaborating with NRC's Board on Life Sciences. When the project is launched in early 2007, the two Boards will begin work on convening a committee of appropriate experts. There will likely be some membership overlap with the BMAP committee.

BPA staff member Timothy Meyer led a discussion of a potential review of a plan for U.S. fusion community involvement in the ITER science program. Inspired by a letter from DOE Under Secretary for Science Raymond Orbach to the National Academies, the study would evaluate the preliminary planning exercise outlined in a document prepared by the U.S. Burning Plasma Organization and help frame it in a broader context.

With Wendy Freedman and Roger Angel, BPA staff member Brian Dewhurst led a discussion on a potential update of the 1990s report on the federal funding of astronomy. The new study might also focus on the increasing importance of public/private partnerships in ground-

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Committees of the Board on Physics and Astronomy

Beyond Einstein Program Assessment Committee
Charles F. Kennel, Scripps Institution of Oceanography, and Joseph H. Rothenberg, Universal Space Network, *Co-chairs*

Committee on Astronomy and Astrophysics[1]
C. Megan Urry, Yale University, and Charles L. Bennett, Johns Hopkins University, *Co-chairs*

Committee on Biomolecular Materials and Processes[2]
Arup Chakraborty, Massachusetts Institute of Technology, *Chair*

Committee on Radio Frequencies
Paul A. Vanden Bout, National Radio Astronomy Observatory, *Chair*
Jeffrey Piepmeier, NASA Goddard Space Flight Center, *Vice Chair*

Condensed-Matter and Materials Physics 2010 (CMMP 2010)[3]
Mildred S. Dresselhaus, Massachusetts Institute of Technology, and William J. Spencer, SEMATECH, *Co-chairs*

MRSEC Impact Assessment Committee
Matthew V. Tirrell, University of California at Santa Barbara, *Chair*

NASA Astrophysics Program Assessment Committee[1]
Kenneth H. Keller, University of Minnesota, *Chair,* and Martha P. Haynes, Cornell University, *Vice Chair*

Materials Synthesis and Crystal Growth Committee
Paul S. Peercy, University of Wisconsin at Madison, *Chair*

Plasma Science 2010[3]
Steven Cowley, University of California at Los Angeles, and John Peoples, Fermi National Accelerator Laboratory, *Co-chairs*

Plasma Science Committee
Riccardo Betti, University of Rochester, *Chair*

Rare-Isotope Science Assessment Committee
John F. Ahearne, Sigma Xi and Duke University, and Stuart J. Freedman, University of California at Berkeley, *Co-chairs*

Solid State Sciences Committee
Peter F. Green, University of Michigan, *Chair,* and Barbara Jones, IBM Almaden Research Center, *Vice Chair*

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[1]Joint with Space Studies Board
[2]Joint with Board on Life Sciences
[3]Elements of the new survey *Physics 2010*

Rare-Isotope Science (continued from page 1)

(2016, according to current DOE plans). Despite the uncertainty inherent in predicting what will be the important scientific questions in the far future, a powerful new rare-isotope facility could resolve scientific issues of clear importance.

A rare-isotope facility produces beams of unstable atomic nuclei for direct study or can use them in subsequent reactions to produce even more exotic nuclear species. The committee identified several key science drivers.

Nuclear structure. A FRIB would offer a laboratory for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a more broadly applicable theory of nuclei will emerge. FRIB would investigate new forms of nuclear matter such as the large neutron excesses occurring in nuclei near the neutron drip line, thus offering the only laboratory access to matter made essentially of pure neutrons; a FRIB might lead to breakthroughs in the ability to fabricate the super-heavy elements with larger neutron numbers that are expected to exhibit unusual stability in spite of huge electrostatic repulsion.

Nuclear astrophysics. A FRIB would lead to a better understanding of key issues by creating exotic nuclei that, until now, have existed only in nature's most spectacular explosion, the supernova. It would offer new glimpses into the origin of the elements, which are produced mostly in processes very far from nuclear stability and which are barely within reach of present facilities. A FRIB would also probe properties of nuclear matter important to theories of neutron-star crusts.

Fundamental symmetries of nature. Experiments addressing questions of the fundamental symmetries of nature will similarly be conducted at a FRIB through the creation and study of certain exotic isotopes. These nuclei could enable important experiments on basic interactions because aspects of their structure greatly magnify the size of the symmetry-breaking processes being probed. For example, a possible explanation for the observed asymmetry between matter and antimatter in the universe could be studied by searching for a nonzero permanent electric dipole moment larger than Standard Model predictions in heavy radioactive nuclei.

The committee concluded that nuclear structure and nuclear astrophysics constitute a vital component of the nuclear science portfolio in the United States. Failure to pursue a U.S. FRIB would likely lead to a forfeiture of U.S. leadership in nuclear-structure-related physics and would curtail the training of future U.S. nuclear scientists.

The committee concluded that a U.S. facility for rare-isotope beams of the kind described to the committee would be complementary to existing and planned international efforts (see figure), particularly if based on a heavy-ion linear accelerator. With such a facility, the United States would be a partner among equals in the exploration of the world-leading scientific thrusts listed above. The committee concluded that the science addressed by a rare-isotope facility, most likely based on a heavy-ion driver using a linear accelerator, should be a high priority for the United States.

The committee's final report was publicly released on Friday, December 8, 2006, in unedited, prepublication form. The co-chairs gave a public presentation in Chicago at a morning session of the Nuclear Science Advisory Committee's task force on radioactive-isotope beams. The event was attended by more than 40 people and was featured in an article in the Chicago Tribune. ■

Rare-Isotope Science Assessment Committee

John F. Ahearne, *Co-chair*
Sigma Xi and Duke University

Stuart J. Freedman, *Co-chair*
University of California at Berkeley

Ricardo Alarcon
Arizona State University

Peter Braun-Munzinger
GSI

Adam S. Burrows
University of Arizona

Richard F. Casten
Yale University

Yanglai Cho
Argonne National Laboratory (retired)
[Unable to participate because of illness]

Gerald T. Garvey
Los Alamos National Laboratory

Wick C. Haxton
University of Washington

Robert L. Jaffe
Massachusetts Institute of Technology

Noemie B. Koller
Rutgers University

Stephen B. Libby
Lawrence Livermore National Laboratory

Shoji Nagamiya
Japan Proton Accelerator Research Complex

Witold Nazarewicz
University of Tennessee

Michael Romalis
Princeton University

Paul Schmor
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Michael C.F. Wiescher
University of Notre Dame

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Materials Synthesis and Crystal Growth

Natalia J. Melcer, BPA Staff

Under the auspices of the Solid State Sciences Committee of the Board on Physics and Astronomy, a new study committee is being formed to assess the status of new materials synthesis and crystal growth (MSAC) in the United States and to identify areas of opportunity for future research. This study will identify and articulate the role that MSAC plays in advancing research in condensed-matter and materials physics and the physical sciences in general, highlight new opportunities that are intellectually exciting and ripe for scientific breakthroughs, and outline enhancements to the materials research enterprise that will improve the productivity and capability for MSAC. Further, U.S. capabilities in this area will be benchmarked against foreign competition. Other factors to be considered include the historical roles of industry, university, and government laboratories in MSAC, the role of crystal growth for both scientific and commercial applications, and the professional status of crystal growers in the United States. Specifically, the committee is charged with the following tasks:

1. Define the research area of new materials and crystal growth, framing the activities and intellectual impact in the broader context of the condensed-matter and materials sciences.

2. Assess the health of the collective U.S. research activities in new materials and crystal growth.

3. Articulate the relationship between the synthesis of bulk and thin-film materials and measurement-based research; identify appropriate trends.

4. Identify future opportunities for new materials and crystal growth research and discuss the potential impacts on other sciences and society in general.

5. Recommend strategies to address these opportunities, including discussion of the following issues: (a) existing efforts to improve accessibility to and distribution of samples; (b) technology transfer from basic research to commercial processes; (c) essential elements of nationally-coordinated materials synthesis capabilities; and (d) domparisons to levels of effort in other countries

Several issues frame this study and relate to the U.S. capability to create and characterize new materials. First, the basic research capability of U.S. industry is waning, and with it, the domestic capability for creating new materials and growing them in crystalline form suitable for characterization and analysis. Second, materials characterization capabilities are very strong and growing. Third, the opportunity to exploit strong U.S. characterization capabilities for the identification of materials with new properties is constrained by the limited domestic supply of new materials. And finally, strong capabilities for new materials creation have emerged in Japan and Europe, placing the United States at a competitive disadvantage. Given the rise of these issues, a study is timely to articulate a vision forward for the field to capitalize on current expertise and characterization capabilities in the United States.

The activities falling under MSAC are broad: They span traditional academic disciplines such as chemistry, materials science, and physics, and they are spread over different types of institutions such as university, government, and industrial research labs. They also span subject matter such as electronic, magnetic, optical, and structural phenomena. MSAC impacts areas of research such as superconductors, novel magnets, low-dimensional systems, quantum-critical systems, optical materials, and semiconductors.

Going forward, the committee will conduct its first data-gathering meeting at the National Academies' Keck Center in Washington, D.C., early in 2007. At this meeting, the committee will hear from its sponsors, the National Science Foundation and the Department of Energy, and other stakeholders. The committee is also planning town hall meetings for broad community input on this topic at professional society meetings in 2007. To create a robust future for condensed matter science and technology and fully enable its role in fueling the U.S. economic engine, this study will address the needs of the MSAC field and recommend strategies for realizing its full potential.

The chair of the NRC has recently appointed members to the committeee. The committee will be led by Paul Peercy, Dean of Engineering at the University of Wisconsin. Fifteen other experts in science, engineering, and policy will fill out the committee. ■

Materials Synthesis and Crystal Growth Committee

Paul Peercy, *Chair*
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Collin Broholm
The Johns Hopkins University

Robert Cava
Princeton University

James Chelikowsky
University of Texas at Austin

Zachary Fisk
University of California at Irvine

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National Institute of Standards and Technology

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University of Illinois at Urbana-Champaign

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CMMP 2010 Interim Report

Natalia J. Melcer, BPA Staff

On September 14, 2006, the CMMP2010 committee released its interim report, *Condensed-Matter and Materials Physics: The Science of the World Around Us,* summarizing eight challenges for condensed matter and materials physics in the coming decades. CMMP 2010 is part of the Board on Physics and Astronomy's *Physics 2010* survey of all the branches of physics. Two reports in the physics survey have been completed to date: *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics* and *Controlling the Quantum World*.

The CMMP 2010 committee, chaired by Mildred S. Dresselhaus (MIT) and William J. Spencer (SEMATECH, retired), is charged to review recent accomplishments and new opportunities in the field; identify potential future impacts on other scientific fields; consider how CMMP contributes to meeting national societal needs; identify, discuss, and suggest priorities for construction, purchase, and operation of tools and facilities; examine the structure and level of the current research effort and funding; and make recommendations on how to realize the full potential of CMMP research.

The committee received broad input on its charge through town meetings held at the March meeting of the American Physical Society, the spring meeting of the American Chemical Society, and the spring meeting of the Materials Research Society. Committee members also conducted small focus group sessions at various institutions around the country for informal discussion on the future of CMMP research.

To address its charge, the committee released an interim report highlighting eight challenges that frame the future of the field. Meeting these challenges will lead to significant advances in both fundamental science and materials-based technology. Highlights from the eight challenges identified by the committee follow:

1. How do complex phenomena emerge from simple ingredients? Most materials are made of simple, well-understood constituents, and yet their aggregate behaviors are stunningly diverse and often deeply mysterious. The relationship between the properties of the individual and the behavior of the whole is very subtle and difficult to uncover and lies at the heart of CMMP. The challenge is to understand how collective phenomena emerge, to discover new ones, and to determine which microscopic details are unimportant and which are essential.

2. How will we generate power in the future? Our nation must develop cheap, renewable energy sources to reduce our dependence on fossil fuels while minimizing carbon emissions and other harm to the environment. Promising technologies for solar energy, hydrogen fuel cells, solid state lighting, rechargeable batteries, and improved nuclear power will play critical roles, but we also need fundamentally new approaches. To meet our needs, many profound scientific challenges require urgent attention. CMMP is strongly positioned to help address these challenges. Investment over a broad front and collaboration with other disciplines and policy makers are needed to meet this immense challenge.

3. What is the physics of life? The study of living matter poses special challenges for CMMP because the constituent biomolecules are far more complex than the atoms or molecules that form most materials. CMMP will continue to catalyze advances in biology and medicine by providing new methods for quantitative measurement. At the same time, the study of biological systems broadens the horizons of physics. The unparalleled specificity and robust functioning of biomolecular systems generate new theoretical ideas and inspire the creation of novel materials and devices. In its ability to analyze complex systems by identifying their essential and general features, physics will be indispensable in sifting through the vast trove of accumulating data to tackle the origins of the ultimate emergent phenomena: life and consciousness.

4. What happens far from equilibrium and why? Isolated systems evolve toward equilibrium, a state in which properties do not change with time. Yet much of the richness of the world around us arises from systems far from equilibrium. Phenomena such as turbulence, earthquakes, fracture, hurricanes, and life itself occur

See "CMMP 2010" on page 14

Committee on Condensed-Matter and Materials Physics 2010

Mildred S. Dresselhaus, ***Co-chair***
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William J. Spencer, ***Co-chair***
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Controlling the Quantum World

Michael H. Moloney, NMAB Staff

Ed. Note: This article is largely inspired by the Executive Summary of the report.

Atomic, molecular, and optical (AMO) science demonstrates powerfully the ties of fundamental physics to society. Its very name reflects three of 20th century physics' greatest advances: the establishment of the atom as a building block of matter; the development of quantum mechanics, which made it possible to understand the inner workings of atoms and molecules; and the invention of the laser. Navigation by the stars gave way to navigation by clocks, which in turn has given way to today's navigation by atomic clocks. Laser surgery has replaced the knife for the most delicate operations. Our nation's defense depends on rapid deployment using global positioning satellites, laser-guided weapons, and secure communication, all derived directly from fundamental advances in AMO science. Homeland security relies on a multitude of screening technologies based on AMO research to detect toxins in the air and hidden weapons in luggage or on persons, to name a few. New drugs are now designed with the aid of x-ray scattering to determine their structure at the molecular level using AMO-based precision measurement techniques. And the global economy depends critically on high-speed telecommunication by laser light sent over thin optical fibers encircling the globe. These advances, made possible by the scientists in this field, touched many areas of societal importance in the past century, and AMO scientists have been rewarded with numerous Nobel prizes over the past decade, including the 2005 prize in physics.

Controlling the Quantum World: The Science of Atoms, Molecules, and Photons is the latest volume in the *Physics 2010* decadal survey. It concludes that research in AMO science and technology is thriving and it identifies, from among the many important and relevant issues in AMO science, six broad grand challenges that succinctly describe key scientific opportunities available to AMO science.

(1) Revolutionary new methods to measure the nature of space and time with extremely high precision have emerged within the last decade from a convergence of technologies in the control of the coherence of ultrafast lasers and ultracold atoms. This new capability creates unprecedented new research opportunities.
(2) Ultracold AMO physics was the most spectacularly successful new AMO research area of the past decade and it led to the development of coherent quantum gases. This new field is poised to make major contributions to resolving important fundamental problems in condensed matter science and in plasma physics, bringing with it new interdisciplinary opportunities.
(3) High-intensity and short-wavelength sources such as new x-ray free-electron lasers promise significant advances in AMO science, condensed matter physics and materials research, chemistry, medicine, and defense-related science.
(4) Ultrafast quantum control will unveil the internal motion of atoms within molecules and of electrons within atoms to a degree thought impossible only a decade ago. This is sparking a revolution in the imaging and coherent control of quantum processes and will be among the most fruitful new areas of AMO science in the next 10 years.
(5) Quantum engineering on the nanoscale of tens to hundreds of atomic diameters has led to new opportunities for atom-by-atom control of quantum structures using the techniques of AMO science. There are compelling opportunities in both molecular science and photon science that are expected to have far-reaching societal applications.
(6) Quantum information is a rapidly growing research area in AMO science and one that faces special challenges owing to its potential application in data security and encryption. Multiple approaches to quantum computing and communication are likely to be fruitful in the coming decade, and open international exchange of people and information is critical in order to realize the maximum benefit.

See "Quantum World" on page 9

Committee on Atomic, Molecular, and Optical Physics 2010

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University of Illinois at Urbana-Champaign

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BPA Meeting
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based astronomy.

Near the end of the afternoon, Martha Haynes described the NRC review of the Board by its parent, the Division on Engineering and Physical Sciences. The Board underwent a similar review three years ago. As part of the review, letters will be sent out to the Board's sponsors, other stakeholders, and past members to solicit feedback on the BPA.

Closing the day, invited guest Daniel Savin reviewed a recent NASA workshop on laboratory astrophysics. He said that the astronomy community needs additional spectroscopic data for higher precision interpretation of current observations. The Board speculated about the scope of a potential NRC study and discussed the role that it might play in this area. There are clear connections from laboratory astrophysics to astronomy, AMO science, and plasma physics.

The next day of the Board meeting opened with a report from Roger Blandford on the NSF "senior review" of the ground-based astronomy program. Professor Blandford reviewed the key findings and recommendations of the report. Astronomy is poised for dramatic advances in the understanding of the universe. Realizing this potential requires continual life-cycle investment in increasingly complex and expensive NSF-supported ground-based facilities while maintaining basic grant support. Fiscal constraints continue to limit the ability to initiate new projects and to operate all existing facilities at their current levels of support. Dr. Blandford's committee had the daunting task of evaluating the relative merits of the diverse array of NSF-funded observatories. The committee's report emphasized that realistic planning is essential and, going forward, a coherent national astronomy enterprise will be crucial.

As co-chair of the Board's Committee on Astronomy and Astrophysics, C. Megan Urry led a discussion about the next astronomy and astrophysics survey. She described a white paper that her committee is developing that charts several options for the timing and implementation of the survey. This advisory paper discusses, for instance, options for handling the increasingly long lead time required for development of large facility projects as well as strategies for dealing with uncertain cost risks. The discussion will continue with the broader community at a special session planned for the January 2007 meeting of the American Astronomical Society.

The autumn 2006 meeting of the Committee on Radio Frequencies was held in Socorro, New Mexico at the Very Large Array Operations Center (image courtesy D.B. Lang).

Paul Peercy presented an update on the Materials Synthesis and Crystal Growth Committee that is being formed under the auspices of the Board's Solid State Sciences Committee (see related article in this issue).

Committee on Radio Frequencies member David DeBoer then reviewed the activities of the committee and the pending launch of its own decadal-style scientific assessment project. The study will examine the current scientific uses of the electromagnetic spectrum and will frame the future outlook for both the research and policy-making communities.

The Board then discussed several emerging topics in which it could play a potential role in the future. In the area of fostering innovation in the physical sciences through partnerships among government, university, and industry, Joseph Hezir and Thomas Theis made several observations. They suggested that the BPA might help to examine the situation by looking at a case study in condensed-matter and materials research and assessing the opportunities for connecting the research programs across the three different sectors.

Erich Ippen presented some preliminary thinking about the topic of quantum information science; the field has moved dramatically forward and includes much more than just quantum computing and cryptopgraphy.

Finally, James Brau discussed a potential role for the BPA in helping to organize an international symposium on superconducting radio-frequency technology. This new technology is playing an important and international role in the design of major new accelerators for a wide variety of purposes, ranging from materials physics and nuclear physics to high-energy particle physics.

With a warm thank-you to everyone for participating, Professor Sargent adjourned the meeting. The Board will meet next in Washington, D.C., on April 27-28, 2007. ■

Quantum World (continued from page 7)

Surmounting these challenges will require important advances in both experiment and theory. Each of these science opportunities is linked closely to the new tools that will also help in meeting critical national needs. The key future opportunities for AMO science presented by these six grand challenges are based on the rapid and astounding developments in the field, a result of investments made by the federal R&D agencies in AMO research programs. These compelling grand challenges in AMO research are discussed in more detail in the report, which also highlights the broad impact of AMO science and its strong connections to other branches of science and technology and discusses the strong coupling to national priorities in health care, economic development, the environment, national defense, and homeland security.

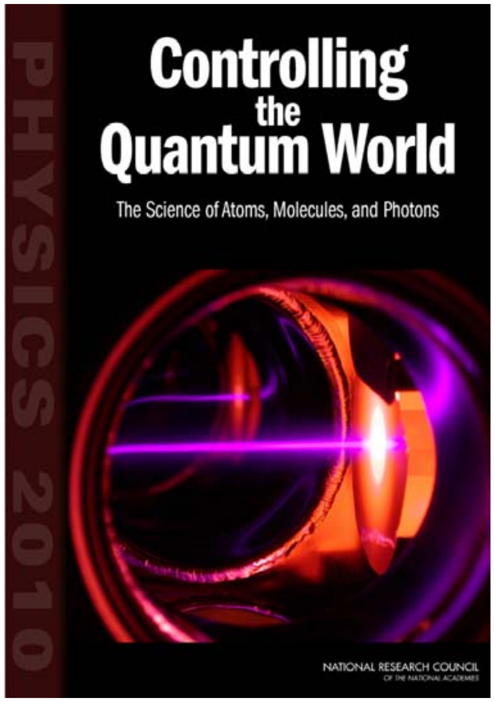
The report offers 10 conclusions on government support for AMO science based on data on funding, demographics, and program emphasis collected from federal agencies:

(1) Given the budget and programmatic constraints, the federal agencies questioned in this study have generally managed the research profile of their programs well in response to the opportunities in AMO science. In doing so, the agencies have developed a combination of modalities (large groups; centers and facilities; and expanded single-investigator programs). Much of the funding increase that has taken place at DOE, NIST, and NSF has been to benefit activities at research centers. The overall balance of the modalities for support of the field has led to outstanding scientific payoffs.

(2) The breadth of AMO science and of the agencies that support it is very important to future progress in the field and has been a key factor in its success so far.

(3) Since all of the agencies report that they receive many more proposals of excellent quality than they are able to fund, it is clear that AMO science remains rich with promise for outstanding future progress. AMO science will continue to make exceptional advances in science and in technology for many years to come.

(4) In view of its tremendous importance to the national well-being broadly defined—that is, to our nation's economic strength, health care, defense, education, and domestic security—an enhanced



investment program in research and education in physical science is critical, and such a program will improve the country's ability to capture the benefits of AMO science.

(5) Historically, support for basic research has been a vital component of the nation's defense strategy. Therefore, the recent decline in funding for basic research at the defense-related agencies is troubling.

(6) The extremely rapid increase in technical capabilities and the associated increase in the cost of scientific instrumentation have led to very significant added pressures (over and above the usual Consumer Price Index inflationary pressures) on research group budgets. In addition, not only has the cost of instrumentation increased but also the complexity and challenge of the science make investigation much more expensive. This "science inflator" effect means that while it is now possible to imagine research that was unimaginable in the past, finding the resources to pursue that research is becoming increasingly difficult.

(7) In any scientific field where progress is extremely rapid, it is important not to lose sight of the essential role played by theoretical research. Programs at the federal agencies that support AMO theory have been and remain of critical importance. NSF plays a critical and leading role in this area, but its support of AMO theoretical physics is insufficient.

(8) AMO science is an enabling component of astrophysics and plasma physics but is not adequately supported by the funding agencies charged with responsibility for those areas.

(9) The number of American students choosing physical science as a career is dangerously low. Without remediation, this problem is likely to create an unacceptable "expertise gap" between the United States and other countries.

(10) Scientists and students in the United States benefit greatly from close contact with the scientists and students of other nations. Vital interactions include the training of foreign graduate students, international collaborations, exchange visits, and meetings and conferences. These interactions promote excellent science, improve international understanding, and support the economic, educational, and national security needs of the United States.

Finally, the report offers six recommendations motivated by its findings on the science opportunities and the programmatic conclusions that form a strategy to realize fully the potential at the frontiers of AMO science:

(1) In view of the critical importance of the physical sciences to national economic strength, health care, defense, and domestic security, the federal government should embark on a substantially increased investment program to improve education in the physical sciences and mathematics at all levels and to strengthen significantly the research effort.

(2) AMO science will continue to make exceptional contributions to many areas of science and technology. The federal government should therefore support programs in AMO science across disciplinary boundaries and through a multiplicity of agencies.

See "Quantum World" on page 10

Ethanol
(continued from page 1)

cellulosic ethanol.

A Red Herring: The Net Energy Balance of Corn Ethanol

The lower heating value for ethanol is measured to be 21.2 MJ/L. Naturally, we then ask, How much energy does it take to produce a liter of ethanol? The Farrell study estimates that the agricultural phase of corn ethanol costs around 5.5 MJ (nearly half of which comes from fertilizers containing nitrogen) and the biorefinery phase costs around 15.2 MJ (more than 90% of which comes from coal and natural gas use). The net energy balance is, so far, positive and tiny (+0.5 MJ), but there is still one missing component of the equation: coproducts.

The production of ethanol from corn necessarily involves the production of carbon dioxide and food products (e.g., dried distiller grains) which can be used to feed livestock. These coproducts have a market value and displace energy use elsewhere, so Kammen et al. allot an energy credit of 4.1 MJ/L. This leaves the energy balance at +4.6 MJ for each liter of ethanol produced. Failing to consider coproducts, as well as using older farming data, has led other groups to claim a negative energy balance.

One thing all of the studies agree on is that ethanol reduces the consumption of petroleum, and the Farrell group estimates the reduction to be around 95%. This comes at the cost of increasing our dependence on coal and natural gas, however.

Looking CO_2, CH_4 and N_2O emissions, the Kammen group calculates that, in terms of global warming potential, for each MJ of ethanol produced, distributed and combusted, the equivalent of 77 grams of CO_2 are emitted. The estimated uncertainty for this calculation ranges from +29% to -36%, which places it within error bars of the greenhouse gas (GHG) emissions from gasoline use, which are calculated to release the equivalent of 94 grams of CO_2 for each MJ.

The focus on the question of whether the net energy balance is positive or negative has led many in the public to believe that this is the relevant question for determining whether we should be making and subsidizing corn ethanol. But even the scientists who calculate a positive net energy balance remain skeptical that corn ethanol is a long-term solution. The relatively small energy gain, the uncertain status of GHG emissions, and issues like soil erosion and effects on food prices remain worrisome.

A Potential Solution: Cellulosic Technology

One potential way forward is cellulosic technology. This approach breaks cell walls down into, among other things, cellulose and lignin. Lignin, a combustible material, can be used instead of coal and natural gas to power biorefinery plants while designer enzymes can be used to break cellulose down into sugars.

To illustrate the promise of cellulosic ethanol Kammen's group simulated what the lifecycle of cellulosic ethanol might look like if switchgrass were used as a biomass crop. Switchgrass has several virtues: It uses water efficiently, is indigenous to the Great Plains, and is already used by farmers to help control soil erosion. Furthermore, increased use of switchgrass would not affect food prices.

Agricultural costs for growing switchgrass are also less than for growing corn, and lignin can be burned to power the biorefinery plants, so the total energy costs for cellulosic ethanol come out to only 3.2 MJ/L (compared with 20.7 MJ/L for corn). And, of course, there is an energy coproduct credit of 4.8 MJ/L, which leads to a +22.8 MJ net energy balance. This would indicate an energy output more than eight times greater than the energy input. Though these numbers come from preliminary estimates for how a biorefinery based on cellulosic technology might perform, the results are very encouraging.

Along with a significantly better net energy balance, this scenario reduces GHG emissions by an estimated 88% compared with emissions from gasoline. Unfortunately, with no commercial plants in operation, these estimates are highly uncertain. Additionally, it is not clear how expensive the enzymes being developed will turn out to be.

The Big Picture

In 2004, the United States consumed 140 billion gallons of gasoline and 3.4 billion gallons of ethanol, while a demonstration plant from the Iogen Corporation in Ottawa, Canada, produced only 1 million gallons of cellulosic ethanol. Clearly, cellulosic ethanol will not play a large role in our energy budget any time soon.

The U.S. Department of Energy (DOE) has set a goal of using biofuels, primarily ethanol, to reduce gasoline consumption 30% by 2030. A recent joint study by the U.S. Department of Agriculture and DOE (April 2006) concluded that the United States does indeed have the land resources to produce enough biomass to meet more than one-third of the current demand for transportation fuels. The study did not consider potential advances in cellulosic technology and did not try to estimate effects on U.S. GHG emissions.

When I asked staff members at the Academies what they considered ethanol's future to be, several seemed to enjoy bringing to my attention all of the ethanol studies published in the 1970s—only to be forgotten just a few years later. Time will tell if this latest push for ethanol has lasting momentum. ■

Quantum World
(continued from page 9)

(3) Basic research is a vital component of the nation's defense strategy. The Department of Defense, therefore, should reverse recent declines in support for 6.1 research at its agencies.

(4) The extremely rapid increase in the technical capability of scientific instrumentation and its cost has significantly increased pressures (over and above the usual Consumer Price Index inflationary pressures) on research budgets. The federal government should recognize this fact and plan budgets accordingly.

(5) Given the critical role of theoretical research in AMO science, the funding agencies should reexamine their portfolios in this area to ensure that the effort is at proper strength in workforce and funding levels.

(6) The federal government should implement incentives to encourage more U.S. students, especially women and minorities, to study the physical sciences and take up careers in the field. It should continue to attract foreign students to study physical sciences and strongly encourage them to pursue their scientific careers in the United States. ■

Other Selected Activities at the National Academies

T.I. Meyer, BPA Staff

In addition to the Board on Physics and Astronomy, the National Research Council of the National Academies is comprised of more than 75 other boards. Some of their ctivitiesof interest to the physics and astronomy community are described here.

The Academies' Committee on Science, Engineering, and Public Policy convened a committee to investigate the status of women in academia, focusing on science and engineering departments. Led by Donna Shalala, president of the University of Miami, the study committee published its final report, *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering,* in September 2006. The report was covered in a wide variety of media outlets and added to the important national discussion. The committee developed findings about and recommendations for recruiting, hiring, promoting, and retaining women scientists and engineers in academe. The report provides specific action points for faculty, department chairs and deans, academic leaders, funding organizations, higher education organizations, scientific and professional societies, journals, and government officials.

The NRC's Board on Chemical Science and Technology recently released a report entitled *Visualizing Chemistry: The Progress and Promise of Advanced Chemical Imaging.* Scientists and engineers have long relied on the power of imaging techniques to help see objects invisible to the naked eye and thus to advance scientific knowledge. Chemical imaging has a variety of applications for almost every facet of our daily lives, ranging from medical diagnosis and treatment to the study and design of material properties in new products. To continue receiving benefits from these technologies, sustained efforts are needed to facilitate understanding and manipulation of complex chemical structures and processes. By linking technological advances in chemical imaging with a science-based approach to using these new capabilities, it is likely that fundamental breakthroughs in our understanding of basic chemical processes in biology, the environment, and human creations will be achieved. This report reviews the current state of chemical imaging technology, identifies promising future developments and their applications, and suggests a research and educational agenda to enable breakthrough improvements. The report highlights advances in chemical imaging that could have the greatest impact on critical problems in science and technology.

At the end of November 2006, the NRC's Space Studies Board (SSB) convened a workshop to broadly discuss the success and impact of its host of decadal surveys for each of the fields of space science. A three-day public workshop was held that featured invited presentations and discussions on the use of NRC decadal surveys for developing and implementing scientific priorities in astronomy and astrophysics, planetary science, solar and space physics, and Earth science. The workshop addressed lessons learned from the most recent surveys in these fields and potential approaches for future surveys so as to enhance their realism, utility, and endurance. A factual summary of what occurred at the workshop is in preparation.

The NRC's Board on Chemical Sciences and Technology is undertaking a study examining benchmarks in chemical sciences and engineering. Under the leadership of George Stephanopolous (MIT), the committee is performing an international benchmarking exercise to determine the standing of the U.S. research enterprise relative to its international peers in the field of chemical engineering. The benchmarking exercise will address the following questions: (1) What is the position of U.S. research in chemical engineering relative to that in other regions or countries? (2) What are the key factors (human resources, equipment, infrastructure, etc.) influencing relative U.S. performance in chemical engineering? (3) On the basis of current trends in the United States and worldwide, extrapolate to the U.S. relative position in the near and longer-term future. The project is sponsored by NSF.

The NRC's National Materials Advisory Board recently completed the first review of the National Nanotechnology Initiatve (NNI), *A Matter of Size: Triennial Review of the NNI*. The NNI was created in 2000 to focus and coordinate the nanoscience and nanotechnology research and development activities being funded by several federal agencies. To take stock of the progress of the NNI, Congress, directed the NRC to carry out a review of the program every 3 years. This report presents the results of the first of those reviews, which addresses the economic impact of nanotechnology developments and provides a benchmark of U.S. research and development efforts relative to those undertaken by foreign competitors. In addition, the report offers an assessment of the current status of responsible development of nanotechnology.

The NRC's Board on Mathematical Sciences and their Applications has convened a committee that will examine the demand for high-end computing and data-intensive computation in four fields of science and engineering (astrophysics, atmospheric sciences, evolutionary biology, and chemical separations and reactor engineering). The study will (1) review the most pressing scientific questions and technological problems identified for those fields in other sources (e.g., decadal surveys); (2) identify the subset of those challenges for which an extraordinary advancement in understanding is difficult or impossible without cutting-edge computation-intensive and/or data-intensive capabilities; (3) identify some of the likely impacts of making progress on as many of these scientific questions and technological problems as possible and the contribution that computation-intensive and data-intensive capabilities can make to that progress; and (4) identify and categorize the mathematical and algorithmic characteristics of these important scientific questions and technological problems. The committee will also identify, where possible, those characteristics that cut across disciplines. The project is sponsored by the National Coordination Office for Networking and Information Technology Research and Development in the Executive Office of the President. ■

Beyond Einstein Program Assessment Committee

Brian D. Dewhurst, BPA Staff

In fall 2006, NASA and the Department of Energy (DOE) requested that the Space Studies Board (SSB) and BPA initiate a study to assess the five missions of the Beyond Einstein program and recommend one for first development and launch. This study is now under way, and is expected to be released in September 2007.

The NRC's 2000 astronomy and astrophysics decadal survey, *Astronomy and Astrophysics in the New Millennium*, identified a number of key scientific goals. Among these were to determine the large-scale properties of the universe—the amount, distribution, and nature of its matter and energy, its age, and the history of its expansion; to understand the formation and evolution of black holes; and to study the dawn of the modern universe, when the first stars and galaxies formed.

A subsequent NRC report, *Connecting Quarks with the Cosmos*, identified the science connections between the fields of astronomy and astrophysics and fundamental physics. In 2003, building on these reports, NASA and the astronomy and astrophysics communities prepared a roadmap entitled "Beyond Einstein: From the Big Bang to Black Holes" and proposed a set of five space science missions, including two Einstein Great Observatories (Constellation-X and the Laser Interferometer Space Antenna) and three Einstein Probes (Inflation Probe, the Joint Dark Energy Mission, and the Black Hole Finder Probe). These missions address dark energy, black holes, gravitational radiation, properties of the cosmic microwave background radiation, and other science questions. The Beyond Einstein program also includes technology development, theory, and education programs to support the flight missions. In addition, the DOE's Office of Science has had a growing interest in exploring questions about dark energy and dark matter, as evidenced in the NRC report, *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics*. DOE has sought a means for exploring dark energy and has funded research for a potential dark energy probe, and both NASA and DOE have taken steps toward a joint NASA-DOE Joint Dark Energy Mission (JDEM).

While the NRC has recommended all five of these missions in either *Astronomy and Astrophysics in the New Millennium* or *Connecting Quarks with the Cosmos*, the NRC has never prioritized all five missions in this suite.

In response to a NASA "funding wedge" that is expected to open in fiscal year 2009, NASA and DOE requested that the NRC assess the five Beyond Einstein missions and recommend one for first launch and development. This NRC study will use a set of criteria, including potential scientific impact and technical readiness, to examine the five Beyond Einstein missions.

Statement of Task

The committee is charged to address the following tasks:

1. Assess the five proposed Beyond Einstein missions (Constellation-X, Laser Interferometer Space Antenna, Joint Dark Energy Mission, Inflation Probe, and Black Hole Finder Probe) and recommend which of these five should be developed and launched first, using a funding wedge that is expected to begin in FY 2009. The criteria for these assessments include: (a) Potential scientific impact within the context of other existing and planned space-based and ground-based missions; and (b) Realism of preliminary technology and management plans, and cost estimates.

2. Assess the Beyond Einstein missions sufficiently so that they can act as input for any future decisions by NASA or the next Astronomy and Astrophysics Decadal Survey on the ordering of the remaining missions. This second task element will assist NASA in its investment strategy for future technology development within the Beyond Einstein Program prior to the results of the Decadal Survey.

This NRC study will use a set of criteria, including potential scientific impact and technical readiness, to examine the five Beyond Einstein missions. The committee will be holding four town hall meetings across the country in order to gather input from interested members of the science community. The first of these meetings will be held February 1st, in Irvine, CA.

Committee Membership

Reflecting the broad appeal of the science addressed by the Beyond Einstein mission suite, the NRC's Beyond Einstein Program Assessment Committee includes both physicists and astronomers as well as several project-management specialists with expertise in planning, costing, and executing space-based science projects. The committee is co-chaired by Charles F. Kennel and Joseph H. Rothenberg. Dr. Kennel is Distinguished Professor and former director at the Scripps Institution of Oceanography and director of the Environment and Sustainability Initiative at the University of California, San Diego. Mr. Rothenberg is currently president and a member of the board of directors of Universal Space Network. He spent 17 years with Grumman Aerospace and held a number of spacecraft development, test, operations, and management positions for both the Solar Max Mission and Orbiting Astronomical Observatory projects.

Community Engagement

The committee is obtaining input on Beyond Einstein mission concepts at its data-gathering meetings and is seeking broader input from the science community through a series of Town Hall meetings. These town hall meetings will take place during February and March 2007 across the country. The first meeting will be February 1, 2007, at Arnold and Mabel Beckman Center of the National Academies in Irvine, California. Additional town-hall meetings will be scheduled for Chicago, Boston, and Baltimore. These meetings are open to the public, and advance registration is suggested for those planning to make specific remarks; open-microphone sessions will be included as well.

Additional information can be found on the committee's website at <http://ww7.nationalacademies.org/bpa/Beyond_Einstein.html>. ■

Beyond Einstein Program Assessment Committee[1]

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[1]Joint study of the SSB and BPA

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Christine Mirzayan Graduate Fellowship Program

The Christine Mirzayan Science & Technology Policy Graduate Fellowship Program of the National Academies is designed to engage graduate science, engineering, medical, veterinary, business, and law students in analysis that informs the creation of science and technology policy and to familiarize them with the interactions of science, technology, and government.

Each fellow is assigned to a senior staff member who acts as his or her mentor. The mentor provides guidance and ensures that the fellow's time is focused on substantive projects and activities. In addition, the fellows are briefed by organizations in Washington other than the National Academies who influence, make, or report on science and technology (S&T) policy.

A key activity of the fellowship program is a seminar series that is developed, designed, and implemented by the fellows themselves. Fellows select three science and technology policy topics to be the basis of debate-style seminars. They then break into groups to refine the topic, determine the category and identification of speakers, and develop a plan of action. This exercise helps fellows gain a better understanding of the dynamics of committees like National Academies committees and of the challenges of putting together an activity similar to a congressional hearing.

After the first week, the fellows training and educational experience continues and includes weekly events such as lunches with each of the three Academies' presidents, field trips, briefings, as well as seminar series development and collaboration. Fellows are encouraged to independently seek activities outside the National Academies as well. These activities often include congressional hearings, seminars at other think tanks, shadowing federal officials or others involved in S&T policy.

The fellows' educational activities encompass all of these activities as well as the activities within their program unit. For more information on eligibility and to apply for the fellowship, please see the fellowship online at <http://www7.nationalacademies.org/policyfellows/index.html>. ■

BPA Online Presence Grows in 2006

T.I. Meyer, BPA Staff

The BPA's online presence is anchored by its Web site at <http://www.nas.edu/bpa> and, according to a recent analysis of Web usage statistics, is growing in popularity as a destination that offers real value to online "surfers."

Filtering out NRC internal traffic and applying modest selection criteria to extract the number of "visits" to the BPA Web site, one finds that over 120,000 visitors stopped in 2006, compared to almost 105,000 visits in 2005. Although the "hits" statistic is now considered passe, the BPA Web site scored more than 600,000 hits in 2006. By comparison, the BPA website recorded almost 105,000 visits in 2005.

What interests online visitors? The most popular pages include the homepages for the BPA and the Committee on Astronomy and Astrophysics, the 1995 report on biomolecular materials, and the online description of the *Physics 2010* survey, each scoring thousands of individual page views.

By far, the most popular file to be downloaded has been the unedited prepublication version of the EPP2010 report, *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics*, which scored more than 33,000 downloads in just two months. Perhaps surprising, electronic copies of science presentations to the BPA's Solid State Sciences Committee take an easy second and third places.

From where do BPA Web site vistors hail? About 30% come from overseas, and the top domain types are .com, .net, and .edu. The prevalence of the .com visitors probably indicates the indexing of visits from various search engines.

In any event, enjoy your visit to the BPA Web site, but should you have comments, please direct them to bpa@nas.edu. ■

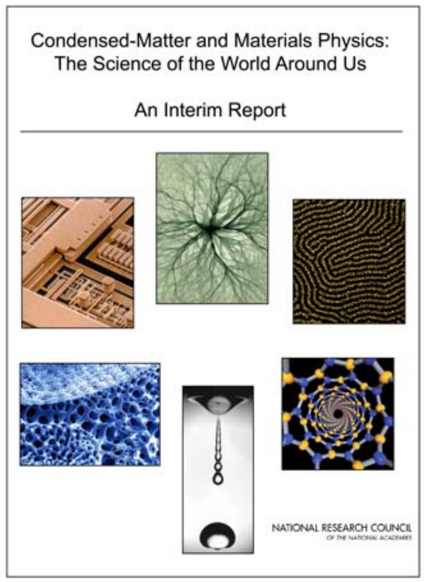
CMMP 2010
(continued from page 6)

far from equilibrium. While much is understood about systems at or near equilibrium, we are just beginning to uncover the basic principles governing such systems. Breakthroughs in this area of CMMP research would affect virtually every discipline in the physical sciences, the life sciences, and engineering.

5. What new discoveries await us in the nanoworld? Nanometer-scale materials straddle the border between the molecular and the macroscopic. They are small enough to exhibit quantum properties reminiscent of molecules but large enough for their size and shape to be designed and controlled. Furthermore, many of the atoms in a nanoscale object are on the surface, available to catalyze chemical and biological reactions and alter nearly every material property. Understanding the physical and conceptual challenges of nanoscale materials will transform the field from a frontier science to a mature discipline and will have a revolutionary impact on fields from materials to information, and from energy to biology.

6. How can we extend the frontiers of measurement and prediction? The quest to observe, predict, and control the arrangements and motions of the particles that constitute condensed-matter systems is central to the CMMP enterprise. The constituent particles span an enormous range of sizes, and their motions span a correspondingly immense range of time scales. As a result, the experimental, computational, and theoretical tools required to study them are extremely diverse. Technical innovations that extend the limits of measurement and prediction lie at the forefront of CMMP research. As CMMP researchers seek to answer fundamental questions about materials, they will continue to design tools that will benefit CMMP, other scientific disciplines, and society at large.

7. How do we revolutionize the information age? Extrapolation of Moore's law suggests that, in the next 20 to 30 years, electronic circuit elements will shrink to the size of single atoms. Even before this fundamental limit is reached, electronic circuits will have to operate in a new regime in which quantum mechanics cannot be ignored. New approaches to communications and information processing will have to be invented, and CMMP will work with other disciplines to enable this transition. CMMP, the science that launched



the information age, will play a pivotal role in determining its future.

8. How can we inspire and teach others? CMMP describes and shapes the world we see. Many of us benefit from the torrent of new and improved electronic devices, but few are aware that these products are the fruits of a rich and coherent scientific discipline characterized by an inseparable mix of fundamental and applied research. Limited public awareness and understanding of science present an increasing danger to our nation's economic security and are most dramatically reflected in the current crisis in primary and secondary school science education. We must now extend our educational efforts not only to improve general scientific literacy but also to increase the pool of students interested in science and engineering. It is critical that we infuse a new generation of scientists with the knowledge, skills, creativity, versatility, and sense of wonder needed to meet the challenges ahead.

The interim report concludes with both optimism and concern: "Domestic funding for basic research in CMMP has been essentially flat for the past decade. The field is growing, as evidenced by the increase in total publications, but the U.S. output remains flat.... CMMP is an important area because of its tight coupling to society, economic growth, and national objectives.... To remain among the world leaders in CMMP, the United States should be participating more fully in the growth of the field.... The U.S. research community still benefits from the science conducted and the scientists trained years ago; the lower levels of current funding will have increasing impact in the future.

"The challenges presented in this interim report outline some of the exciting questions that will drive the continued vitality and growth of CMMP in the coming decades. The fundamental scientific questions, the close interplay between theoretical and experimental research, and the technological applications that will contribute to solving important societal problems all drive enthusiasm in the field....With sufficient resources, the United States will strengthen an indispensable component of the nation's capacity for economic competitiveness—its leadership in CMMP basic research."

The interim report can be downloaded free of charge at <http://newton.nap.edu/catalog/11730.html.> The BPA encourages all interested parties to review the interim report and provide feedback to the committee by e-mail at cmmp2010-input@nas.edu. Please note that all comments submitted will be available for public viewing. A compilation of all public comments will be posted on the committee's Web site at <http://www7.nationalacademies.org/bpa/CMMP2010.html>.

The committee's final report will supply more details, analyze the structure of the current effort, and provide recommendations. The final report will be issued in spring 2007. This study is supported by NSF and DOE. ■

BPA Mission

The Board on Physics and Astronomy (BPA) was created in 1983 as the successor to the National Academy of Sciences Office of Physical Sciences. Several standing committees were assigned at that time to the BPA, including the Committee on Atomic, Molecular, and Optical Sciences, the Solid State Sciences Committee, and the Committee on Radio Frequencies. Later, the Committee on Astronomy and Astrophysics and the Plasma Science Committee were created in response to requests from the scientific community. Since its inception, the BPA has published more than 40 reports, workshops, and collaborative activities, including two surveys of physics and two surveys of astronomy.

The important questions in physics and astronomy change as we learn more about nature, and that rate of change has been increasing. The BPA seeks to inform the government and the public regarding important scientific opportunities and issues as well as the changing nature of science. It builds bridges between the evolving subdisciplines of physics and astronomy and with other areas of science. The BPA is successful if it helps the science community and society understand what is needed to advance physics and astronomy and why doing so is important.

Every activity of the BPA is aimed at accomplishing one or more of the following goals:

- Monitor the health of physics and astronomy.
- Identify trends in research and new developments at the scientific forefronts.
- Foster interactions with other fields and cooperation among academic disciplines.
- Strengthen connections to technology.
- Facilitate effective service to the nation.
- Improve public understanding of science.
- Encourage cooperation among federal agencies, government laboratories, and universities involved in research in physics and astronomy.

Approaches for achieving these objectives include the following:

- Periodic assessments of major fields. By setting priorities, these surveys provide programmatic guidance to agencies.
- Response to particular needs and requests from federal agencies, both those that have programs of research and those that play an administrative role.
- Continuing surveillance of scientific progress and identification of issues and problems in various fields. Several standing committees are focused on this task.
- Cross-disciplinary studies of special areas that lie at the intersection of several disciplines.
- Many scientific assessments address the benefits that accrue to society through technology development that follows from the pursuit of science.

BPA Update: Emerging Projects

• *Committee on Atomic, Molecular, and Optical Science (CAMOS).* With the completion of the decadal survey of atomic, molecular, and optical (AMO) science, the BPA's standing committee is poised to become active in monitoring and implementing the agenda outlined in the report *Controlling the Quantum World*. Operating guidelines will include the following objectives: (1) to provide a means by which federal agencies can obtain technical information and assistance from the NRC; (2) to initiate and oversee the conduct and publication of studies concerning AMO science and its multidisciplinary connections with other fields of science and technology; (3) to provide a forum for discussion among AMO scientists and thereby provide a unifying force for this diverse and varied field; and (4) to provide an interface for communication among the subfields of the AMO science community and the staff of federal agencies that support research in the field.

• *Gravitational Physics 2010.* Following the elements of *Physics 2010* that examined particle physics, plasma science, condensed-matter and materials physics, and atomic, molecular, and optical science, the BPA is pursuing an assessment of and outlook for gravitational physics. The study would encompass laboratory tests of the equivalence principle as well as astrophysical phenomena such as massive black holes and gravitational radiation.

• *Review of a Plan for U.S. Fusion Community Participation in ITER.* Following up on activities called for in the Energy Policy Act of 2005, a committee of about 10 members will be convened to review and evaluate the document "Planning for U.S. Fusion Community Participation in the ITER Program." The committee will determine whether the plan provides a good initial outline for effective participation of U.S. plasma scientists in research at ITER and recommend next steps for further development of the plan. The committee will prepare a concise report.

New Faces at the BPA. As noted on the front page, elementary particle theorist Matthew Bowen spent three months with the BPA as part of the National Academies' Christine Mirzayan Science and Technology Graduate Fellowship program. Matthew's appointment ended in late November 2006. We are also pleased to announce that Caryn J. Knutsen joined the BPA staff in October 2006 as a senior program assistant; with a background in physics and mathematics, Caryn brings enthusiasm and strong skills to the office.

BPA Update: Meetings in 2007

January 2007	
01/28-29	CMMP 2010 Faciliies workshop, Irvine, Calif.
01/30-31	CMMP 2010 meeting, Irvine, Calif.
01/30-02/01	Beyond Einstein meeting, Irvine, Calif.
April 2007	
04/5-7	Beyond Einstein meeting, Chicago, Ill.
04/13-14	PLSC meeting, Washington, D.C.
04/19-20	SSSC meeting, Washington, D.C.
04/25-26	CORF meeting, Washington, D.C.
04/27-28	BPA meeting, Washington, D.C.
May 2007	
TBD	CAA meeting, Washington, D.C.
September 2007	
9/29-30	PLSC meeting, Irvine, Calif.
October 2007	
10./18-19	SSSC meeting, Irvine, Calif.
November 2007	
11/3-4	BPA meeting, Irvine, Calif.

THE BPA Web site at **www.national-academies.org/bpa** provides news on recently released reports and other developments as well as a link to this newsletter in PDF format. Reports may be ordered at **www.nap.edu**.

Recent Reports:

Controlling the Quantum World
Condensed-Matter and Materials Physics: The Science of the World Around Us
Scientific Opportunities with a Rare-Isotope Facility in the United States

Coming Soon:

Final Report of the Plasma 2010 Committee
Final Report of the CMMP 2010 Committee
Final Report of the MRSEC Impact Assessment Committee

Board on Physics and Astronomy
The National Academies
Keck Center, 922
500 Fifth Street, N.W.
Washington, DC 20001

BPA Newsletter for: