BPA NEWS

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Neal Lane Addresses BPA at its Washington Meeting

At the meeting of the Board on Physics and Astronomy that took place in Washington on April 25, Neal Lane, Director of the National Science Foundation, shared his views on the outlook for science in general and for the NSF in particular. He made the following main points.

"We live in a remarkable era—a 'golden age of discovery' in science and engineering. Every day we read, see, and hear news of advances from research and education.

"The past few months have been quite exciting for science. As you know, we recently learned that a team at MIT created the first atom laser, which may one day make it possible to manipulate and focus individual atoms at scales much smaller than the wavelengths used in optical lasers.

"We continue to marvel at the possibilities brought by new materials. Research directly related to the Nobel prize-winning work on buckyballs has now brought us 'nanotubes' which appear to be many times stronger than steel but have only a fraction of the weight.

"For the first time, researchers were able to clone an adult mammal, Dolly, the world's most famous lamb. She has become an instant star, and in no small way, the pictures of her we've seen in the news have become a symbol for the larger impact of science and technology on our society. Some of us in society are intimidated by what is happening, others are invigorated by it, but virtually none of us can ignore it.

"Naturally, given this event and others, many people are asking if science is going too far too fast.

"Science in our nation is often viewed from extreme perspectives. On the one hand, many in the public think of science, perhaps with the exception of biomedical research, as abstract and peripheral to addressing our societal needs.

"On the other hand, we in the research community have been known to think of it as the ultimate activity for a civilized society.

I think many of us would agree it is at neither extreme. It is neither peripheral to what happens in the nation nor is it the single-handed solution for our nation's success and prosperity. Rather it is a significant and integral enabler of what America's future will be.

"At the National Science Foundation, our Strategic Plan for the future involves supporting the best research and best people we can find, using merit review, in a way that helps the United States to maintain its world leadership in science and engineering.

"Indeed discoveries are occurring across all areas of science. That is one of NSF's major objectives, to extend the frontiers of research and education throughout all fields of science and engineering. We have always been known for

See "NSF" on Page 2

In this issue:

NAS Holds Second Cosmology Colloquium: *The Age of the Universe, Dark Matter, and Structure Formation*

by David Schramm, University of Chicago, Colloquium Chair, and Marc Davis, University of California

The National Academy of Sciences recently sponsored a two-day Colloquium on "The Age of the Universe, Dark Matter, and Structure Formation." The Colloquium was held on March 21-23, 1997, at the Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering in Irvine, California. It was attended by 88 scientists and two reporters representing the full range of individual scientific disciplines that contribute to cosmology.

The purpose of the colloquium was to address progress in the three interconnected problems which have the center stage in modern physical cosmology today. They are: (1) The Age of the Universe, (2) The Dark Matter of the Universe, and (3) The Formation of Structure in the Universe. New experimental and observational data have dramatically changed the nature of each of these problems and more sharply defined the issues since the last NAS cosmology colloquium, which was held in 1992. These data have helped to consolidate the trend in cosmology toward a multidisciplinary science solidly grounded in observations.

Astronomers have known for 70 years that the Universe is expanding, but there is a continuing controversy over the expansion rate (known as the Hubble constant). The inverse of this rate is a simple measure of the age of the Universe.

See "NAS Colloquium" on Page 3

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.

NSF (Continued from Page 1)

our high standards of excellence and for supporting high-risk, cutting-edge research. And, we are pledged to continue to do just that.

"However, in an uncertain budget climate, retaining such lofty goals is quite challenging.

"As well, we're working to maintain and establish partnerships with state, industry, and academic institutions.

"Perhaps even more exciting than the rich array of discoveries and advances emerging from science and engineering is the wealth of possibilities and opportunities that they are bringing to our economy and society. These new discoveries are no doubt the results of our investments in science and engineering and from the economic standpoint, the returns to society have been enormous.

"Many of us in government, industry, and academia know that investments, public and private, in research and development pay off handsomely into society in many ways, including economic benefits. It has worked that way for decades, but until the last several years we primarily had anecdotal evidence.

"Now, economists confidently note that industries as diverse as agriculture, aeronautics, computers, biotechnology, and medical equipment grew strong and dominant as a result of federal investments in science and technology. In fact, many leading economists now estimate that over the past 50 years, science and technology innovation has been responsible for half of our nation's economic growth.

"Whether or not our economy will continue to grow over the next several years is uncertain and depends to a significant degree on the level of funding for science and engineering in research and education.

"We can no longer expect public support for science and engineering research in the form of a blank check and an undefined agenda. The goal of the taxpayer-supported science and engineering budget is to uplift and improve the nation and its citizenry through the discovery and application of new knowledge. A viable budget is a necessary means to reaching that goal.

"Fortunately for us, NSF fared well this fiscal year in the Presidential budget receiving a three percent increase to just under $3.4 billion.

"An agency that receives a modest increase is being described as a great success. I am pleased that in the President's budget proposal to the Congress, science overall also went up over two percent. Still, the scientific and engineering community is functioning under severely constrained budgets.

"Tradeoffs are toughest in the physical sciences—in part because of priority shifts in other agencies and in industry, but the physical sciences are also where opportunities are both promising and intellectually exciting.

"There are other kinds of tradeoffs we have to consider—for example, between numbers of people and facilities and institutions.

"Those tradeoffs and opportunities are among the things we are here to talk about today. So, I'll stop and begin hearing from you."

At this point, Dr. Lane asked for questions from BPA members and guests. A few highlights of the question-and-answer session, which covered a broad range of issues, follow.

Q: There's much talk in Washington about interdisciplinary science, also called innovative science. Yet NSF has no organizational facilities of such science. I, for example, represent the field of biophysics and I don't know anyplace in NSF where I can go for support.

Lane: It is a very important question you ask and I get the question often because the perception in the community is that we do not have the structure to receive such proposals. The perception is correct—we do not. By that I mean we have no NSF-wide office that routinely receives all multidisciplinary proposals and deals with them. We do have program officers who work very hard to find partners once those proposals come in, share funding, which is the appropri-

See "NSF" on Page 4

NAS Colloquium (Continued from Page 1)

Thus an important test is to compare the age of the Universe based on the Hubble constant with the ages of its contents, such as the Earth, the oldest stars in the galaxy, or the ages derived from nuclear chronometers. A careful comparison can narrow the acceptable range of several cosmological parameters.

More than 50 years ago, astronomers first pointed out that clusters of galaxies have internal motions so large that they should quickly fly apart, unless there is considerable dark, unseen matter, mixed within the clusters. Now astronomers have shown that dark matter is ubiquitous and that is probably constitutes more than 80% of the mass in galaxies and clusters of galaxies. It could be 95% of the mass density of the Universe. Yet we have no idea of the nature of the dark matter. There exist many constraints that exclude most simple explanations, such as gas clouds or snowballs, or ordinary matter in any form. One current favorite idea is that the dark matter is an elementary particle of a form not yet seen in the laboratory; it is no exaggeration to say that understanding the nature of the dark matter is one of the top priorities of all physical science.

Although the Universe is homogeneous and isotropic on large scales, on small scales it is quite lumpy, with a well-defined filamentary large-scale distribution of galaxies and clusters of galaxies. On still larger scales, small-amplitude fluctuations generate the ripples observed in the Cosmic Microwave Background Radiation (CMBR), first detected by the COBE satellite. All this structure is connected to the physics of the very early Universe, to the cosmological parameters, and to the nature of the dark matter. Tying all the constraints together is the long-term goal of the field.

The detection of anisotropy in the CMBR by the COBE satellite several years ago has been followed by further experiments probing smaller angular scale with sensitive experiments operating at the South Pole, in Canada, and on balloon-borne payloads, all of which have reported the detection of fluctuations in the angular distribution of the radiation. New, more powerful experiments carried on long-duration balloon flights and on new spacecraft will soon provide data of even higher quality. The measured ripples in the CMBR are primarily a remnant from the epoch when the Universe first became transparent to the CMBR, roughly at an age of 100,000 years. The fluctuations in the Universe were much lower amplitude then, so that the perturbations can be accurately described by linear theory. All the CMBR experiments provide a powerful tool for probing structure formation scenarios in the Universe and for differentiating between competing models.

Similar progress has come recently in the dark-matter detection experiments, both from laboratory searches for WIMPs and telescope searches for MACHOs, including the microlensing experiments known as MACHO and EROS. The cosmological parameters, including the Hubble constant and the age of the Universe, continue to be the center of intense focus. New data on Cepheid distances and other indicators from the Hubble Space Telescope (HST) lead to ages which are not easily reconciled with stellar evolution and radioactive dating ages. Hints of progress from the soon-to-be-released data of the Hipparchos satellite will surely play some role in this controversy. And most recently, the use of gravitational lensing and the so-called Sunyaev-Zel'dovich effect have led to dramatic progress on Hubble constant constraints that are independent of the normal astronomical distance ladder. Further constraints on dark matter from satellite x-ray gas observations and from gravitational lensing of clusters of galaxies are growing.

The controversy surrounding proposed mechanisms of formation of galaxies and clusters of galaxies that from which one can deduce statistical properties that match those of the observed data has, if possible, grown more intense. This topic interrelates the microwave anisotropy and dark-matter problems with the observed distributions of galaxies. The

See "NAS Colloquium" on Page 5

Committees of the Board on Physics and Astronomy

Committee on Astronomy and Astrophysics[1]
Marc Davis, University of California at Berkeley; Marcia Rieke, University of Arizona, Cochairs

Committee on Atomic, Molecular, and Optical Sciences
Wendell T. Hill, III, University of Maryland, Chair

Committee on Elementary-Particle Physics
Bruce Winstein, University of Chicago, Chair

Committee on Gravitational Physics
James Hartle, University of California at Santa Barbara, Chair

Committee on Nuclear Physics
John C. Schiffer, Enrico Fermi Institute, Chair

Committee on Optical Science and Engineering[2]
Charles Shank, University of California at Berkeley, Chair

Plasma Science Committee
Ravi Sudan, Cornell University, Chair

Solid State Sciences Committee
Paul Fleury, University of New Mexico, Chair

Committee on Condensed-Matter and Materials Physics
Venkatesh Narayanamurti, University of California at Santa Barbara, Chair

Committee on Radio Frequencies
Michael Davis, Arecibo Observatory, Chair

U.S. National Committees[3]

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[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.

NSF (Continued from Page 2)

ate thing to do in many circumstances, but that's hard. To review such proposals is hard, and if you're receiving unsolicited proposals at random, then it makes it difficult to use panels, which is almost required for multidisciplinary interactions. We'll all debate that, but that's a place, I think, where a panel approach, getting people in the room from different areas, can really get the job done.

As we speak, we have an activity going on inside the Foundation to try to identify what's the best structure for doing what you just asked. And I don't have that report yet, but I think it's going to be something like this. Every directorate (at least) or maybe every division (we have seven of those representing all of science and engineering) will have a point person. This person will not only have the responsibility to look after such proposals, but also to encourage and reward researchers for taking the initiative to construct multidisciplinary research projects. But let me not speak too far because I don't yet have the recommendations on this.

> "I would say that industrial R&D, on the whole, has not really been cut back."

We have a senior staff group which is responsible for all activities that cut across research, education, and different disciplines. But that's not an operational arm, that's a policy arm. What that group tries to do is identify areas, broad areas, to encourage participation across the Foundation, among different directorates. But I do admit we don't really have a very good structure for receiving an unsolicited multidisciplinary proposal. In fact I think we've been told by program officers "We don't fund that kind of thing." That's not a direct quote, but I think we have given that impression. We have to get away from that because the science is increasingly moving that direction. We're not going to get out of the disciplines, but increasingly the exciting scientific challenges are at the interfaces. We have no choice but to try to deal with this problem.

Q: I have a comment and a question about that. There are really, in some senses, two questions raised here: one is the one that you really responded to which is, how does the foundation deal with new trends, and especially the new trends that are on the interface between the established programs and I guess the ones we've been struggling with for some time.

But biophysics is not exactly a new kid on the block and it does raise another question, specifically, I think, about the relationship between the Foundation and NIH. Really understanding biophysics is a long established field, but it's probably a field which is going to grow, become more important, not less important. There is a giant sister at NIH. It is an example of what you were talking about: there are some new trends and interfaces, but it's more than that, and it raises, in some sense, different issues.

Lane: Let me ask Bob Eisenstein if his advisory committee might have discussed this; I want to make sure I get whatever facts there are on the record before I speak. Bob, can you make a comment?

Eisenstein: I guess one thing I'd like to add, Neal, to what you said is that as you know, yes, there is something called the Office of Multidisciplinary Activities, which for the last three years has been trying hard to find an effective *modus operandi* for handling just those kind of proposals that you spoke of. In the physics division we have a small biological physics program that started about 3-4 years ago. It's about $1 million in overall effort now, and we have a close collaboration with the biology directorate. We have found that in dealing with multidisciplines generally, not only do we have a hard time in the Foundation, but also the community has a difficult time dealing with multidisciplinary proposals. It's very often hard to find an appropriate reviewer base to deal with these things. So, it's a complicated problem.

Q: There's been a marked reduction in industrial research and military research. How does the NSF intend to maintain the proper balance given the lopsided nature of the reduction?

Lane: Yes, I think it is a difficult issue which I've spoken a good bit about internally. NSF is often thought of as the balance wheel. Well, we're not the balance wheel, we never have been, at least not for a very long time. We are 4% of the R&D budget, which is defined rather carefully. You're not going to balance the whole federal R&D with 4% so it is a very difficult issue.

So we keep our focus on the Foundation, on excellence, on peer review, science and engineering research and education, and then we do have to respond as best we can. If DoD made such a big cut in an important area of science and engineering we have no choice but to try and respond to that in an optimized way that does the least amount of damage elsewhere. We won't just turn our backs and say "I'm sorry, DoD was doing that and now they are getting out of it, so that's the end of it." We don't have that attitude about it and we don't have luxury of being able to ignore those cuts.

I would say that industrial R&D, on the whole, has not really been cut back. I expected it to continue to grow substantially after the federal curve turned over, but it has reoriented itself. So, how do we respond to that? I mean, Bell Labs is not doing what Bell Labs did at one time, so how do we deal with that? I don't have a global answer to that. We deal with it somewhat incrementally based on the advice we get from you and the advisory committees and the proposal input from the community. We don't support activities in industrial laboratories except for the very few exceptions that are specialties that we think we can defend in terms of our mission. We support the Small Business Innovation Research (SBIR) program. But, our research and education activities are primarily in universities and colleges and we anticipate that that will continue.■

NAS Colloquium (Continued from Page 3)

dark-matter issues themselves revolve around cosmological nucleosynthesis and the abundances of the light elements, where again new observations (including some with the 10-meter Keck Telescope and with HST) have altered the situation. The combination of these two new tools has also, for the first time, made study of the evolution of the properties of galaxies accessible, as witnessed by the dramatic images of the Hubble Deep Field. A complete cosmological model must properly explain why most galaxies seem to evolve very quickly, while others evolve quite slowly.

The Keck telescope and its high-resolution spectrograph has made possible the collection of superb data detailing absorption lines within diffuse clouds in intergalactic space along lines of sight toward luminous Quasi-Stellar Objects. These primitive clouds, where star formation has been minimal, should contain the primordial abundance ratio of deuterium to hydrogen and provide a strong test of the theory of cosmological nucleosynthesis. The meeting featured a sharp debate over the measured D/H ratio, and while the issue is not fully settled, the measured values of D/H are within the range of the theoretically predicted values, which is an important test of the Big Bang models. These arguments restrict ordinary baryonic matter to make up at most 10% of the critical density of the Universe.

The two science reporters who attended the 1997 colloquium were John Nobel Wilford of the New York Times and Tim Appenzeller of Science Magazine. Wilford wrote a detailed review of the meeting which appeared on the front page of the New York Times on Monday, April 7, 1997, and Appenzeller is working on a story soon to appear in Science.

The 1997 colloquium was organized by a committee consisting of David N. Schramm (University of Chicago, Chairman), P.J.E. Peebles (Princeton University, Co-Chairman), Alan Guth (MIT), Martha Haynes (Cornell), and Bernard Sadoulet (Berkeley). It was planned by a program committee comprised of George Efstathiou (Oxford), John Ellis (CERN), Wendy Freedman (Caltech), Margaret Geller (Harvard), Bernard Pagel (Copenhagen), Martin Rees (Cambridge), Katsuhiko Sato (Tokyo), Rashid Sunyaev (Moscow), Joachim Trümper (Garching), and David Wilkinson (Princeton).

Given the rapid progress in the field and the new data pouring in from a multitude of ongoing and planned experiments, both in space and on the ground, it is very likely that another NAS cosmology colloquium will be appropriate five years from now.■

Cosmology: A Research Briefing (National Academy Press, 1995) is a general introduction to research in cosmology. Written by a panel chaired by Marc Davis, it can be found at www.nas.edu/bpa under "Reports". Printed copies are available gratis from the BPA on request.

BPA Initiates New Studies

The BPA is exploring the need for initiatives in a number of areas. The state of progress on these efforts ranges from "about to launch a study" to "planning a program initiation meeting to get advice from the research community on the pros and cons of carrying out a study." We begin with the former part of that range—with projects that are fairly close to a formal start.

Gravitational Physics.

A panel to carry out a study entitled *Gravitational Physics* has been appointed with James Hartle of the Institute for Theoretical Physics at the University of California at Santa Barbara as chair.

The Panel has been charged to carry out an assessment of the field as part of the new survey, *Physics in a New Era*. Several factors convinced the BPA that this area is ripe for an assessment:

- advances in gravitational physics increasingly depend on experiments that involve large detectors and instruments,
- theoretical progress in areas of gravitational physics that are related to astrophysics more and more depends on large-scale simulations that require collaborations of many scientists, and
- many of the problems of fundamental gravitational physics are becoming those of elementary-particle physics.

There is thus, on the experimental side, a growth in the required scale and resources, and, on the theoretical side, an increase in the connectivity with other areas of physics. For this reason, it is necessary to place these major thrusts of gravitational physics in the context of physics as a whole and to give some sense of priority, both among the various gravity experiments and within the overall physics program. The proposed study aims to do that.

Status of the Field and Scientific Forefronts

Gravity is central to physical phenomena on a wider range of scales than any other force in physics. On the largest scales, gravity governs the evolution of the universe and the large-scale structure exhibited by the galaxies and cosmic background radiation. On the smallest scales it governs the microscopic structure of space-time and plays an indispensable role in current ideas for unified theories of the fundamental interactions.

A number of gravity experiments have reached a critical phase in their development:

- Among the major experimental efforts now under development is a worldwide network of laser interferometers to detect gravitational radiation. The U.S. component of this network is the Laser Interferometer Gravitational-wave Observatory (LIGO), an NSF-funded, joint MIT-Caltech project to construct the most sensitive gravitational-wave detector ever built. LIGO is a pair of large laser interferometers capable of detecting displacements as small as one part in 10^{21}. Its estimated cost, including construction

See "New Studies" on Page 6

New Studies (Continued from Page 3)

and initial operations, is $365 million. The experiment poses a number of significant technological challenges.

• Another major experiment is NASA's Gravity Probe B (GP-B), a space-based attempt to detect the precession induced in an array of super-precise gyroscopes by the spinning of the Earth. This effect is predicted by the General Theory of Relativity (GR), but has not yet been detected directly. The effect, known as frame dragging or gravitomagnetism, is the gravitational analog of the magnetic field generated by a spinning, charged object. GP-B is currently under development at an annual cost of about $50 million.

• The European Space Agency's Laser Interferometer Space Antenna (LISA) would detect gravitational-waves from space. ESA is seeking U.S. participation through NASA. Participation in LISA is a long-range issue, since launch is contemplated in the period 2009-2015. Another potential experiment under study is the proposed U.S.-European Satellite Test of the Equivalence Principle (STEP), designed to test the equivalence of inertial and gravitational mass to one part in 10^{17}.

There are ongoing efforts to test theories of gravity by precision timing of pulsars in binary systems. The existence of several such pulsars increases the prospects for accurate tests of relativistic gravity.

In addition to the above projects, a number of spacecraft and clock experiments to test post-Newtonian relativistic gravity and several solar system experiments, such as Lunar laser ranging, have been proposed; and a variety of laboratory tests are being considered.

The scientific objectives that can be pursued with these instruments, observations, and experiments are quite diverse, and in light of recent progress a reassessment of their role is needed, particularly in view of the major investments that are being made in experimental apparatus.

The major experiments described above are all meant to test various aspects of the General Theory of Relativity (GR). GR is unique among the theories of the fundamental forces of nature in that it is a theory of the geometry of space and time. Because of its special nature, GR occupies a position of great interest in physics. The various gravitational-wave detectors will provide a direct test of GR's prediction of gravitational waves. Further detection of these waves will provide a new window through which the final stages of the collapse of binary star systems and other highly energetic astrophysical phenomena may be observed.

Space and laboratory experiments offer the potential of testing GR to new levels of accuracy. The consideration of the scientific opportunities offered by this diversity of ongoing and potential experiments will be an important focus for the proposed study.

Theoretical research in gravity is also at a critical point in its development. Theoretical questions in Einstein's GR continue to be of great interest especially in the areas of gravitational collapse, black holes, and cosmology. The gravitational-wave detectors now under construction present new theoretical challenges. There is first the problem of *predicting* the gravitational-wave signal expected from realistic astronomical sources, such as coalescing neutron star binaries, to determine what features of theory are being tested by experiment. Then there is the challenge of developing the theoretical tools necessary to *interpret* the detailed information about the sources that is encoded in the detected signal so that gravitational-wave detection becomes a new window on phenomena in the universe. An important question for the study will be whether the scale of present theoretical effort is adequate to support and interpret the results from experiment.

The unification of quantum mechanics and GR—quantum gravity—has long been a major challenge in theoretical physics. A consistent quantum theory of gravity appears to be necessary to a unified theory of the fundamental forces, which is one of the central objectives of modern physics. Quantum gravity is important in the first instants of the universe and is central to the subject of quantum cosmology, which seeks a theory of the initial condition in cosmology. A variety of promising ideas for quantum gravity have been developed in the last decade, notably string theory and non-perturbative quantum gravity. These problems are now being actively worked on by theorists whose background is in elementary particle physics rather than traditional relativity. It will be important for the study to assess these directions and recommend strategies in an area which now overlaps several of the traditional subfields of physics.

Charge

The study will assess the state of scientific progress in gravitational physics as follows:

• Describe the progress in gravitational physics in the last decade.

• Identify the scientifically promising directions for the next decade and describe the experimental, observational, and theoretical resources that are required to pursue these directions.

• Describe the relationship of gravitational physics to neighboring areas of science, in particular, astrophysics, particle physics, cosmology, and mathematics.

• Assess the standing of the U.S. effort in gravitational physics relative to that in other countries and identify opportunities for international collaboration.

• Examine career opportunities for scientists in gravitational physics and the implications for the support of students and postdoctoral researchers.

The objective of the study will be to help the physics community, pertinent government agencies, and the Congress to envision the future of this field in the context of the nation's overall physics effort.

The study is expected to begin in the Fall.

The Impact of Selling the Helium Reserve

Recently, the Congress enacted legislation directing the Department of the Interior to sell off the federal helium reserve. In the same legislation, a National Research Council study of the impact on science and technology was mandated. The BPA is organizing the study in cooperation with the National Materials Advisory Board. The study is

See "New Studies" on Page 11

Physics and Society at the Crossroads

by David Schramm, Robert Dynes, and Don Shapero

Our society is reexamining its priorities as it enters a period characterized on the one hand by reduced expectations for growth and expansion and on the other by tremendous opportunities for greater productivity and functionality. The enhancement of communications and information processing by orders of magnitude is perhaps the most conspicuous example of the latter.

The physics community should participate in this process of reexamination by considering its own goals and priorities. We need to articulated those goals in relation to the broader aims of the country in a way that is fresh, meaningful and persuasive. In this new environment, we cannot take for granted acceptance of a number of ideas that we have treated almost as self-evident—that scientific progress is essential for the welfare of the nation, that expanding the reservoir of scientific knowledge is intrinsically good, and that pursuing science for its own sake is the best way to secure the benefits of research for the country.

To provide a means for the physics community to explore these issues, the Board on Physics and Astronomy is now sponsoring a new decadal survey under the title *Physics in a New Era*. The objectives of the new survey have some elements in common with previous surveys, but also some new elements. The new elements are a response to the BPA's conclusion that both society and the field of physics are at critical junctures.

Previous surveys have focused on documenting the accomplishments of physics and analyzing the requirements for continued progress. To some degree, it has been assumed that physics is a coherent enterprise whose value is already recognized by society. The justification for the nation's physics program has been taken for granted, and we have focused our arguments on the increments needed to expand our research capabilities. But the time has come to look at the physics enterprise from the bottom up and to approach the question of the value of physics to society without relying on the ways of the past.

The frontiers of knowledge in physics have become increasingly challenging to reach, and the costs of expeditions to the forefronts of some areas have mounted. We have tended to assume that society will bear the increasing costs without complaint, even as some of the realms of exploration grow more remote. In the present climate of budget cutting in Washington, it does not seem realistic to rely on the continued growth of the GDP to mask the increasing cost of doing some kinds of forefront physics. We have to confront the question "How can the intellectual vitality of physics best be continued into the next millennium?"

Another topic that bears reexamination is the place of physicists in the labor market. With the expansion of our system of higher education that has taken place over the last 30 years now coming to a close, doctoral recipients find opportunities waning in academe while they are growing in small, high-technology start-up companies and other areas where the physicist's approach to problem solving is useful. Physics departments should think about whether the program that they offer undergraduates and graduate students prepares them with the versatility and flexibility that they will need in rapidly changing labor markets.

In addition to addressing the new problems that physics and society face, the new survey will follow tradition in describing the advances that have occurred since the last survey.[1] It will include a volume on each of the major branches of physics that will identify the priorities for the respective area. But the new survey is carrying out this traditional role in a new way. Past surveys have looked at all the branches of physics at once. While that method has had a great virtue in giving a synchronous snapshot of physics, it has had the disadvantage that it has been difficult to focus attention on particular problems and to follow them up in such a way that action is taken and recommendations are implemented.

This survey therefore breaks with tradition by focusing on a few areas of physics at a time, following up the assessments with an intense implementation effort. A key part of this effort has been cooperation with the appropriate divisions of the American Physical Society in distributing copies of reports to the members of the corresponding division for use in bringing the message to their colleagues in university and industry research settings and even more importantly to the government, including their senators, representatives, and program managers in federal agencies that support research.

The new survey will also include an overview volume that will discuss the unity of physics, its relationships with other fields, and its contributions to national needs. In this volume we will try to take a fresh look at the ways in which society reaps benefits from its investment in physics (and in science in general). The overview will also explore such issues as demographics, career paths, education, and others as discussed in more detail later on in this article.

When a field of science speaks up for itself, there is always the worry that thoughtful recommendations will not be heard because of the suspicion that the research community is thinking more about its own well-being than that of the citizenry generally. We believe that continuing to carry out the survey under the auspices of the National Research Council will help to convince the audience for the report that its advice is broadly based and credible. The Board on Physics and Astronomy itself represents all the branches of physics (and astronomy and astrophysics as well); it therefore can serve, in some sense, as a voice for the community as a whole that does not favor any particular branch of physics over another. Further, the BPA operates under the auspices of the National Research Council and the National Academy of Sciences, with their Executive Branch and Congressional Charters to advise the federal government on science and technology issues. NRC reports are reviewed by panels that include scientists from many different fields. So the survey can give voice in Washington to the priorities of the physics community through a mechanism that is understood

See "Physics Survey" on Page 8

Physics Survey (Continued from Page 7)

by both sides of the dialogue to be even handed, authoritative, and possessing a broad portfolio to advise the government.

In its many consultations with federal officials, the BPA has learned that reports from the Academy do indeed play a special role in communicating the consensus of the scientific community to decision makers in Washington. Of course, broad participation of the scientific community in the process of carrying out assessments and preparing reports is essential for the development and articulation of consensus positions on the important issues in each field. The divisions of the American Physical Society play an important role in this regard, participating in launching studies, providing progress reports to the community through town meetings, and helping to disseminate the results.

That is the general philosophy behind the Board on Physics and Astronomy's program to reexamine physics through a new survey. Let's turn now to some specifics. The survey is being carried out in phases. The first phase (now complete) has produced the several volumes described below.

Phase I

Major Reports:

Atomic, Molecular, and Optical Science: An Investment in the Future.[2] Chairs: Neal Lane and Gordon Dunn.

This report begins with a recognition that "society is asking for greater accountability from scientists and evidence of a return on its investment in scientific research." The charge to the authoring committee was "to review advances of the last decade; determine requirements of the field in the context of national needs such as those related to industrial and technological competitiveness, human health and welfare, environment, defense, energy , and education; establish research and educational priorities from various perspectives; and identify scientific forefronts, technological opportunities, and windows of future opportunity."

The committee found that AMO science is an enabling factor in about 9 percent of the nation's GDP. It recommended a focus on research "that promises new technologies through the invention and development of techniques and instrumentation to better control and manipulate atoms, molecules, charged particles, and light for a broad range of applications and for furthering studies of interactions *at the atomic and molecular level*." It also recommended research leading to new and improved lasers and other advanced sources of light for a broad range of applications.

One response to the study is an increased emphasis at the National Science Foundation on (1) research on control and manipulation of atoms and light at the atomic scale as well as (2) optical science as a multidisciplinary research area. Another response was the undertaking of a major study of optical science and engineering (OSE) that treats the role of OSE in meeting societal needs in the areas of health and medicine; information technology manufacturing; research and education; and environmental, space, and energy technology. That study is being carried out independently of the physics survey by a committee with membership drawn from both the physical sciences and engineering communities that is jointly sponsored by the BPA and the National Materials Advisory Board in the physical sciences and engineering divisions (respectively) of the National Research Council.

The Committee on Atomic, Molecular, and Optical Sciences, a continuing group operating under the auspices of the BPA, initiated this study and played an important role in overseeing the follow-up effort. The American Physical Society's Division of Atomic, Molecular, and Optical Physics distributed 2700 copies of the report to its membership to engage them in the implementation of the recommendations of the report.

Plasma Science: From Fundamental Research to Technological Applications.[3] Chairs: Clifford Surko and John Ahearne.

The authoring committee was charged with assessment of the state of plasma science in the United States and evaluation of its potential to contribute to the technology base of U.S. society. The report concludes that (1) plasmas are pervasive in nature, (2) many of the applications of plasma science are being pursued and exploited effectively. Despite that, *basic plasma science* is not being pursued adequately, and there is no structure in place to assure that the basic plasma science that underlies many applications will be developed. Eventually, this lack will undermine the development of the applications that depend on basic plasma science. The report recommended that basic plasma science be reinvigorated through emphasis on university-scale experimental research programs.

This greater emphasis on basic plasma science was incorporated into the restructuring plan for the fusion program that DOE's Fusion Energy Advisory Committee (FEAC) recommended in January 1996. The study chairs were also invited by the House Science Committee to testify at a March 1996 hearing on the FEAC plan. We are pleased that DOE now plans to allocate a definite fraction of each year's fusion budget to basic experimental plasma science.

The BPA's Plasma Science Committee, a continuing group that initiated this study, has played an important part in overseeing the follow-up effort. The American Physical Society's Division of Plasma Physics distributed 700 copies of the report to its membership to engage them in implementing the report's recommendations.

We are extremely pleased with the impact that these two reports have had in addressing the particular problems of plasma physics and atomic, molecular, and optical physics. They serve as models for the volumes of the physics survey that remain to be completed and demonstrate the effectiveness of the new strategy that we are pursuing.

Research Briefings and Short Reports.

These relatively short reports focus on scientific forefronts.

Research Briefing on Contemporary Problems in Plasma Science and *Research Briefing on Selected Opportunities in Atomic, Molecular, and Optical Sciences* (1991)

These briefings set the stage for the

studies *Plasma Science* and *Atomic, Molecular, and Optical Sciences* discussed above.

Neutrino Astrophysics: A Research Briefing.[4] Chair: John Bahcall.

This report describes the forefronts of the efforts to measure neutrino fluxes from the sun as well as from supernovas. It concludes that these new observational capabilities have opened up a new area of science that can be called *neutrino astrophysics.*

Cosmology: A Research Briefing (1995).[5] Chair: Marc Davis.

This briefing describes the origin, evolution, and possible fates of the universe in a simple, easy-to-understand narrative. It has been used as background material for a number of courses in astronomy and astrophysics at several universities.

Cosmic Rays: Physics and Astrophysics (1995).[6] Chair: Thomas Gaisser.

This report describes how energetic particles from distant regions in the universe bring us information about the processes whereby the particles are accelerated, about dynamical processes in our galaxy and beyond, and about matter and fields in interstellar space. It recommends a number of actions by NASA, NSF, and DOE that are now under consideration.

Phase II

The second phase of the survey (now in progress) treats the following areas:

Elementary-particle physics

A committee chaired by Bruce Winstein of the University of Chicago has been established in consultation with the APS Division of Particles and Fields. The committee, following a pattern set early in the series, is preparing a research briefing that will describe in lay terms the objectives of the field and some of the research forefronts. The committee held a meeting at the DPF's Snowmass96 conference, which provided an opportunity for a broad cross section of the community to interact with the committee. It also gave the committee a sense of the prevailing views regarding the next steps for the field, including U.S. participation in the Large Hadron Collider at CERN as well as concepts for accelerators that would go beyond the reach of the LHC.

Condensed-matter and materials physics.

A committee chaired by Venkatesh Narayanamurti of the University of California at Santa Barbara has carried out a workshop in cooperation with the APS Divisions of Condensed-Matter and Materials Physics that provided broad community input for the study. The committee is conducting an Internet survey of community views that can be accessed through the BPA homepage at www.nas.edu/bpa. The committee has prepared a research briefing that is designed to give a sense of the forefronts of the field to laymen. The BPA's Solid State Sciences Committee, a continuing group that sponsors periodic forums and topical studies, is an active participant in this study.

Nuclear physics.

A committee chaired by John Schiffer of the Enrico Fermi Institute at the University of Chicago has been formed to prepare a study of this area. The APS Division of Nuclear Physics was involved in the initiation of the study. The committee has reviewed the *Long Range Plan* authored by the DOE-NSF Nuclear Science Advisory Committee and is drafting its own report.

Phase III

Phase III will cover several crosscutting areas and will also be concerned with a synthesis (overview).

Biological physics.

To understand how living systems function, one is faced with understanding complex systems and intricate mechanisms. It is rather remarkable that some of the most outstanding books on biology prepared by prominent biologists contain no equations! This fact illustrates the tremendous opportunity for applying physical thoughts and rigor to the field of biology.

There are numerous examples of physicists that have made seminal contributions to biology. A few outstanding examples who received the Nobel Prize for their efforts are Francis Crick, Max Delbrück and Walter Gilbert.

The National Research Council has provided funding for a program initiation meeting to explore the possibilities for a study in this area.

Computational physics.

This is another area where the insight into physical systems interacts with algorithm and machine development to accomplish feats of simulation and computation that could not otherwise be achieved. These accomplishments are playing an increasing role in the progress of physics, and the BPA is exploring the possibility of a study in this area. The NRC has also provided program-initiation funding for this area.

Physics education.

With support from the NRC, Leon Lederman recently convened a group to design the education component of the physics survey. Followup of that meeting is under way.

Overview

Unity of physics

Working in the various branches of physics, we sometimes lose sight of the fact that there is a strong commonality that links the different specialties together. The ties that bind physics into a whole derive partly from the education that all physicists have in common and partly from the style of thinking about problems that physicists learn. How do we nurture an appreciation of the unity of physics as the branches become more specialized? How do we preserve a balance between the reductionism of elementary-particle physics and the search for understanding of complex systems that goes on in condensed-matter physics?

Physics and society

Physics has made many contributions to the economy, but they aren't clearly recognized because, in part, there is no industry that is labeled as the "physics industry". But we might well give that label to (for example) the semiconductor industry, which depends on solid-state physics, chemical physics, plasma physics, materials physics, and so on. And the explosive growth of information technology and telecommunications that is now

See "Physics Survey" on Page 10

Physics Survey (Continued from Page 9)

taking place has its roots in condensed-matter and materials physics of semiconductors as well as fiber optics.

Education

Looking outside the field, physicists need to pay more attention to educating people who will not become physicists—*e.g.*, lawyers, doctors, humanists, and the business and financial community—so they will have a better understanding of the scientific and technological underpinnings of our society. Physics education needs to begin at the K-12 level. By the time most students reach college, they already know that "physics is too hard." Within the field, undergraduate and graduate education should be broader both in terms of subject matter and experience to increase the flexibility of physicists in responding to changing employment patterns.

Connections with other fields of science and engineering

Physics and physicists continue to connect with other areas of science and technology to produce advances. Some examples in biology and medicine include exploring the properties of DNA with optical tweezers, understanding the way proteins are configured, and making improvements in medical imaging (*e.g.*, imaging lungs using laser-polarized noble gases). There are more examples in every field of science.

Demographics and career paths

Doctoral production in physics appears to be at an all-time high. There is mounting concern about employment. Meanwhile, physics departments are noticing decreased enrollments. The community is considering ways to broaden the graduate education experience of physicists to give them the flexibility that they will need in today's job market.

There have been peaks in doctorate production in the past (around 1970, for example), followed by sharp drop-offs. Are we headed for a repeat of that phenomenon? Are there trends in the distribution of subfields? The two most rapidly growing areas appear to be solid-state/low temperature and "general physics". It is important to try to interpret and understand these trends.

International cooperation and competition and the position of U.S. physics relative to that abroad

The next major facility focus for high-energy physics is the Large Hadron Collider at CERN in Geneva. The premier neutron scattering facilities are in Europe. The future of the U.S. fusion program and its role in joint development of facilities with Europe is uncertain. What will the impact of these trends be on U.S. physics?

Emerging crosscutting areas

Interdisciplinary and crosscutting areas are becoming increasingly prominent. For example, optical science and techniques are everywhere. How should physics connect with such fields that draw on many science and engineering disciplines?

The changing environment for physics research

The role of the national laboratories has been reexamined recently by a number of groups. Much of the nation's effort in physics goes on in national laboratories and the potential impact of changes on the physics community is substantial. How do the profound changes in the nature and scale of industrial research affect the distribution of research effort among the traditional major performers (government laboratories, universities, and industry)? As discussed earlier, the role of science and technology in society is changing from a peripheral to a central one. Along with gratifying attention and visibility, the changing role brings demands for a better accounting of what is being done and its value to society.

Funding history and trends

Individual members of the physics community experience increasing difficulty in finding support for research. How much of this trend is due to demographic changes, how much to changes in funding levels, and how much to redistribution of funds in various program categories? Increasingly, there are calls to justify the nation's expenditures on basic research in a quantitative fashion. Perhaps one answer to these calls lies in "endogenous growth theory" propounded by (among others) Paul Romer of the University of California at Berkeley, a physicist turned economist. This theory is an attempt to account for the enormous growth in the economies and output of industrialized countries that has taken place over the last century. Romer says that "Output per hour worked in the United States today is ten times as valuable as output per hour worked 100 years ago." He attributes this change to accumulation of knowledge and expertise in science and technology and improvements in the labor force (due in turn, in part, to better education). He describes this accumulation as a form of capital and prescribes investment in research as an essential policy for promoting growth. Perhaps we should explore the place of physics in "endogenous growth."

Your Role

The target date for completion of the overview is 1999. It will summarize and update all the reports on the individual branches of physics and address topics such as those above that concern physics overall. This part of the physics survey will be the most difficult to write, but also potentially the most valuable.

We welcome suggestions from the community on how to approach this important task. The ideas above are preliminary and meant to stimulate discussion rather than indicate any final conclusions—we hope they will inspire you to write to us at bpa@nas.edu. Continuing input, participation, and help from the physics community is essential.■

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[1] *Physics Through the 1990s*, National Academy Press, 1986.

[2] National Academy Press, 1994. ISBN 0-309-05032-4

[3] National Academy Press, 1995. ISBN 0-309-05231-9

[4] *Nature*, Vol. 375, No. 6526, 4 May 1995, p. 29

[5] This report can be found on the world-wide web at http://www.nas.edu/bpa listed in the "Reports" section. It is also available in printed form from the Board on Physics and Astronomy.

[6] Available from the Board on Physics and Astronomy.

New Studies (Continued from Page 6)

expected to begin in the Fall.

Since 1929 the federal government has operated helium production and purification plants, facilities for helium shipping and pipeline transmission, and (since the 1960s) the world's only underground helium storage facility. The storage facility in Texas maintains the federal helium reserve, which currently consists of about 30 billion standard cubic feet (scf) of government-owned helium. The facility also contains about 4 billion scf of helium stored under contract for private producers. In the United States in 1996, about 2.5 billion scf of helium were consumed, and an additional 850 million scf were produced for export.

Until 1960, the government was the only U.S. helium producer. Today, government production accounts for less than 10% of annual U.S. sales. The government has intentionally set its price higher than the market price to avoid competing directly with private producers, and essentially all government sales in recent years have been to government users or to private distributors that then sell to government users. (The single largest consumer of government-produced helium is NASA, followed closely by the Department of Defense; both use it mostly in preparing space launches.)

In 1996, the Congress passed the Helium Privatization Act of 1996 (P.L. 104-273), which redefines the government's role in the helium market. Among other changes, this act orders the Department of the Interior to begin selling off the reserve by 2005, and requires that all but a small remnant of 600 million scf be completely sold by 2015, in a manner consistent with "minimum market disruption" and at a price given by a formula specified in the act. The formula price for the stored crude helium is almost twice the current market price.

Over the past several decades, the federal helium program has conserved large quantities of helium that would otherwise have been vented to the atmosphere. The Helium Privatization Act hands responsibility for future conservation efforts to the private sector.

The Helium Privatization Act instructs the Department of the Interior to "enter into appropriate arrangements with the National Academy of Sciences to study and report on whether such disposal of helium reserves will have a substantial adverse effect on U.S. scientific, technical, biomedical, or national security interests" (§15(a)).

The Scientific Objectives of the ITER Project

The Department of Energy's Office of Energy Research has asked the National Research Council for an evaluation of the scientific objectives of the International Thermonuclear Experimental Reactor. The questions to be addressed in the study include:

- Is ITER likely to achieve its scientific objectives?
- What new scientific research would ITER make possible?
- What will be the value of ITER's experimental results relative to the objectives of the U.S. fusion energy sciences program?
- How will achieving ITER's scientific objectives contribute more generally to the advancement of U.S. science?

At a recent meeting of the Fusion Energy Science Advisory Committee (a DOE federal advisory committee), Robert W. Conn presented the report of a panel that he chaired entitled "Review of the ITER Detailed Design Report." This report forms the background for the requested NRC report.

The Conn report describes the objectives of ITER as "…to demonstrate controlled ignition and extended burn…," "to demonstrate steady-state operation…" and "…to demonstrate the technologies essential for a fusion reactor…"

The Conn report goes on to say that "ITER brings together three threads important for the advancement of fusion: burning plasma physics, steady-state operation, and the testing of key technologies. It has long been agreed in the U.S. fusion program that the threshold to burning plasma physics occurs at Q = 5, where the alpha heating power equals the externally supplied input power." Achievement of this criterion would constitute a demonstration of scientific feasibility.

The first question posed to the Conn Panel was "Are the ITER physics basis, technology base, and engineering design sound?" The Panel's overall response was "…the ITER engineering design represented in the DDR [Detailed Design Report] is a sound basis for the project to proceed." In making this statement, the Panel pointed out that the DDR does not represent the final design.

The NRC and the DOE are discussing the best way to carry out the NRC study.

Physics Education

Recently a program initiation meeting was convened in Washington by Leon Lederman. The group considered a broad range of issues, including general physics education as well as education for future physicists at the K-12 level, the undergraduate level, and the graduate level. The discussion—recognizing the fact that, among those receiving advanced degrees in physics, most will pursue nonacademic careers—included consideration of the balance between specialized expertise and broad knowledge. The group concluded that a thorough review of physics education should be undertaken as part of the new survey of physics.

Biological Physics

Steve Block of Princeton University is forming a program initiation group to define an assessment of the role of physics in biology (and vice versa). A first meeting of the group is expected in the Fall.

Computational Physics

David Arnett of the University of Arizona is forming a program initiation group to define an assessment of computational physics. See the discussion of this area on page 9.

Physics in a New Era

The topics of education, biological physics, and computational physics will all be covered in one form or another in the new survey of physics, *Physics in a New Era*, chaired by David Schramm. An overview volume that will address physics as a whole is also planned. The new survey of physics is discussed in detail in the article "Physics and Society at the Crossroads" that begins on page 7 of this issue of *BPA News*.■

For news on recently released BPA reports and other developments, see the BPA website at www.nas.edu/bpa.

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